FORGING

PRACTICE

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FORGING PRACTICE

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CONTENTS

INTRODUCTION

THE IMPORTANCE OF FORGING IN MACHINE BUILDING

All machines are built up of parts made of different materials and by various manufacturing processes. Some parts are cast from metals; some are forged, while others are produced by machining on different kinds of machine tools. Castings and forgings have to be machined before they acquire their proper shape, exact dimensions and surface finish. Forged parts, whether they are to be machined or not, are called *forgings.*

Forging processes are *extremely important* in the machine-building industry. No machine, whether simple or complicated, can be built without the use of forgings. It has been calculated that, in the Soviet Union, from 15 to 20 per cent of all the metals produced are subjected to forging; and that about one-third of all the steel smelted in the U.S.S.R. is subjected to forging and stamping. Hammer forging and stamping is particularly widespread in the tractor, automobile, agricultural machinery, ship-building, locomotive building and other industries. For instance, in the railway-car building industry up to 70 per cent of all the parts which go to make a car are forgings. Not only parts of machines, but also many tools are manufactured by forging.

The widespread use of forgings is explained by the fact that forging *improves the quality of steel*, which becomes stronger after forging. For this reason, machine parts which are subjected to heavy duty are generally made of forgings. Moreover, the time required for the manufacture of a part or a tool is very often *reduced* by forging, much less steel is consumed in its production and, consequently, the cost of any given part is reduced. For instance, during the production of a crankshaft weighing 17 kilograms from a bar of rolled steel up to 31.5 kilograms are irretrievably lost as chips in machining. When a crankshaft of the same weight is manufactured by the forging process, only 13.7 kg of steel are lost in chips—i. e., the loss is 56.6 per cent less. Many such examples could be cited.

The enormous importance of forging operations is shown by the fact that nearly every machine shop has a forge division, and every machine-building plant—a forge and stamping shop. This book contains information about the advantages of forging practice and the necessity of employing forging or hot stamping operations in different cases.

CHAPTER

BENCH OPERATIONS

CHISELLING METALS

Blacksmiths often have to do bench-work and use bench tools. The *main bench-work operations* are: marking-out, chiselling, cutting, filing, scraping, grinding-in, drilling holes and cutting threads.

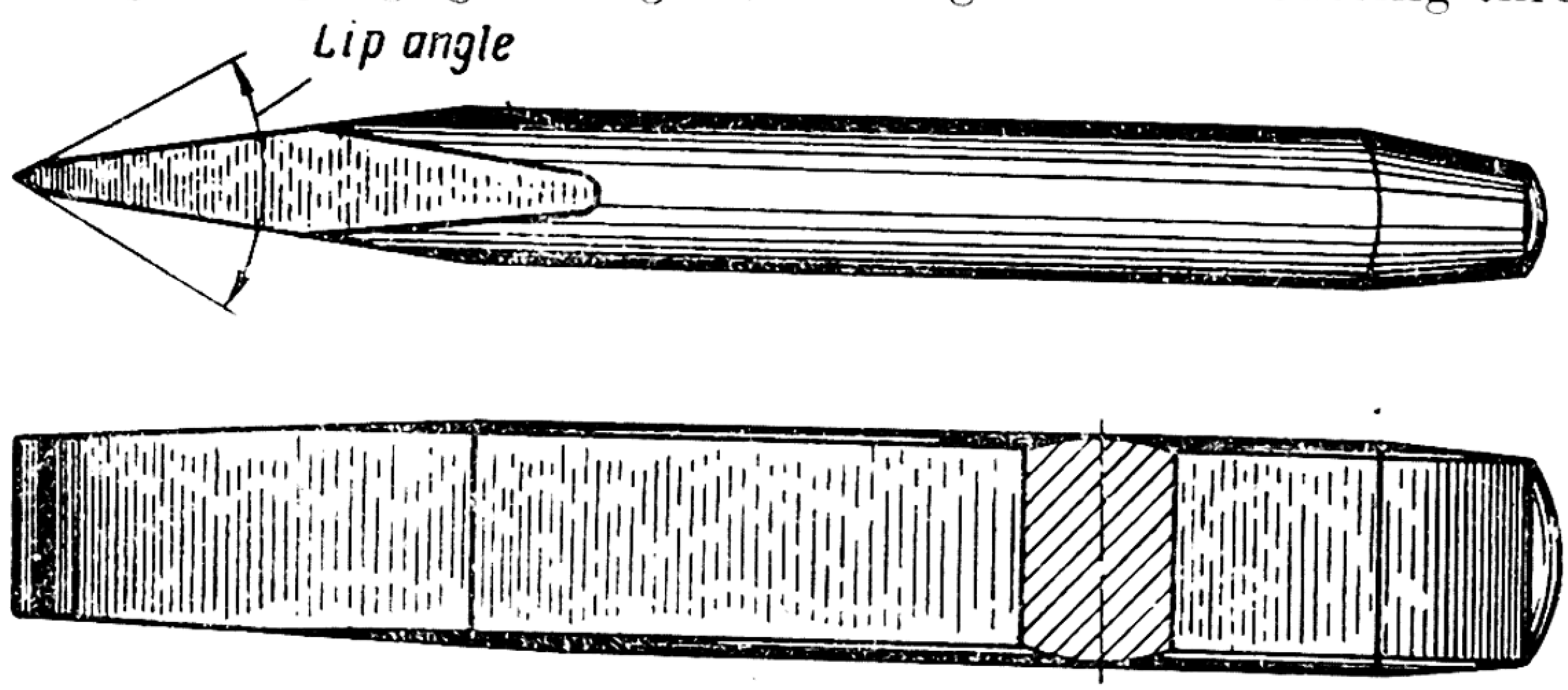


Fig. 1. Flat cold chisel

Most of all blacksmiths' practice entails chiselling metals, filing parts and drilling holes. Let us examine these operations.

The chief tools employed in chiselling metals are: cold chisels, hammers and vises.

Cold chisels are made of carbon tool steel, containing from 0.6 to 0.8 per cent of carbon (Fig. 1). In length, they vary from 100 to 200 mm; their cutting edges are ground to an angle depending on the hardness of the metal to be cut: the harder the metal, the more acute should be the angle. Table 1 gives various *lip angles* of cold chisels for cutting metals of different hardness. The cutting edge of the chisel is hardened.

Table 1

Metal	Lip angle of chisel in degrees
Cast iron and bronze	75
Steel and iron	60
Brass	45
Zinc and aluminium	35

Cape chisels (Fig. 2) are used for cutting narrow grooves such as, for instance, keyways. The *hammer* used for striking the chisel is made of carbon steel containing from 0.4 to 0.6 per cent of carbon.

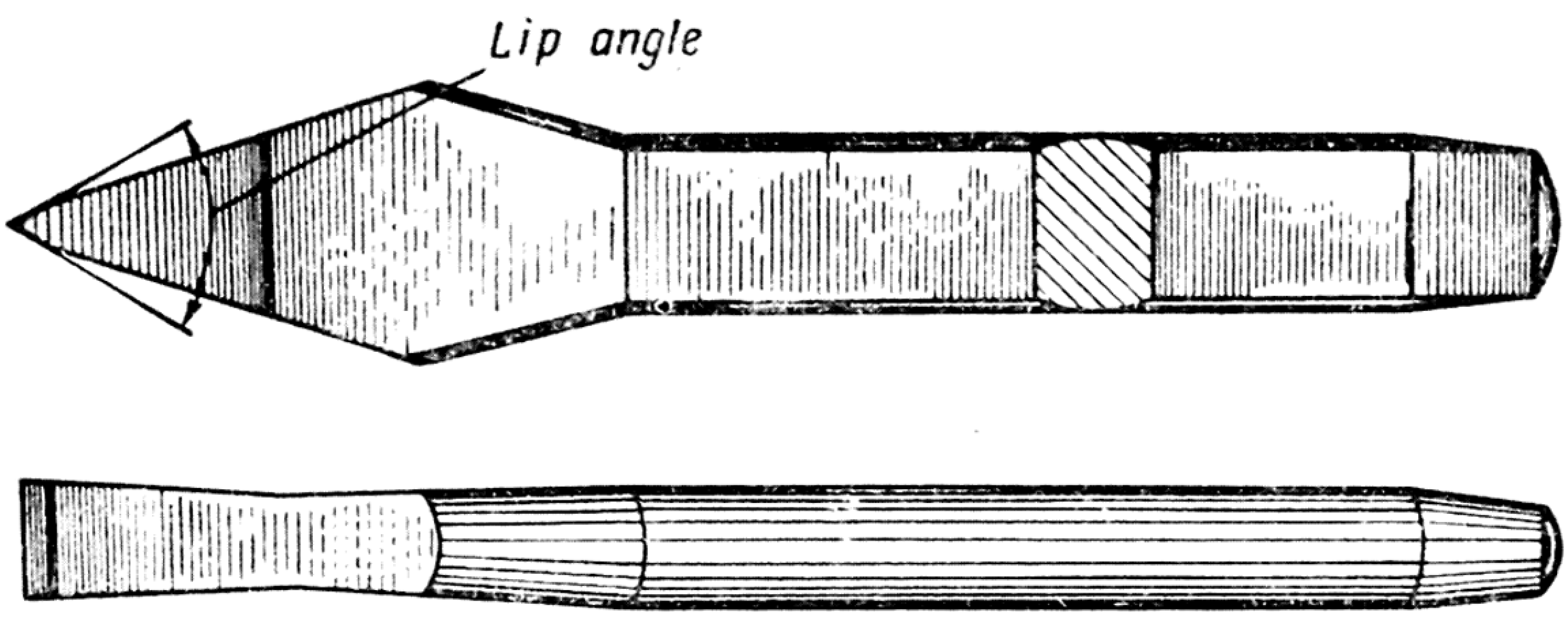


Fig. 2. Cape chisel

The weight of a hand hammer is selected according to the strength of the worker and the size of the chisel. Usually, for cutting operations of average difficulty, hand hammers weighing from 0.4 to 0.6 kg are recommended.

Hammer handles are generally made of hardwood, such as birch or ash; they are from 250 to 300 mm long, and of oval cross-section. The end of the handle is secured in the hammer by means of a steel wedge.

The work is usually clamped in the jaws of a vise, the most common form of which is the *bench vise* (Fig. 3). This type however has the disadvantage that its jaws *A* and *B* are not always parallel, as a result of which the work is gripped only by the upper or lower edge of the jaws, instead of by their entire surface. *Parallel vises* (Fig. 4) do not have this disadvantage as their jaws *T* and *P* are always parallel. In such vises, the work is always gripped by the entire surface of the jaws and, consequently, more firmly than in bench vises.

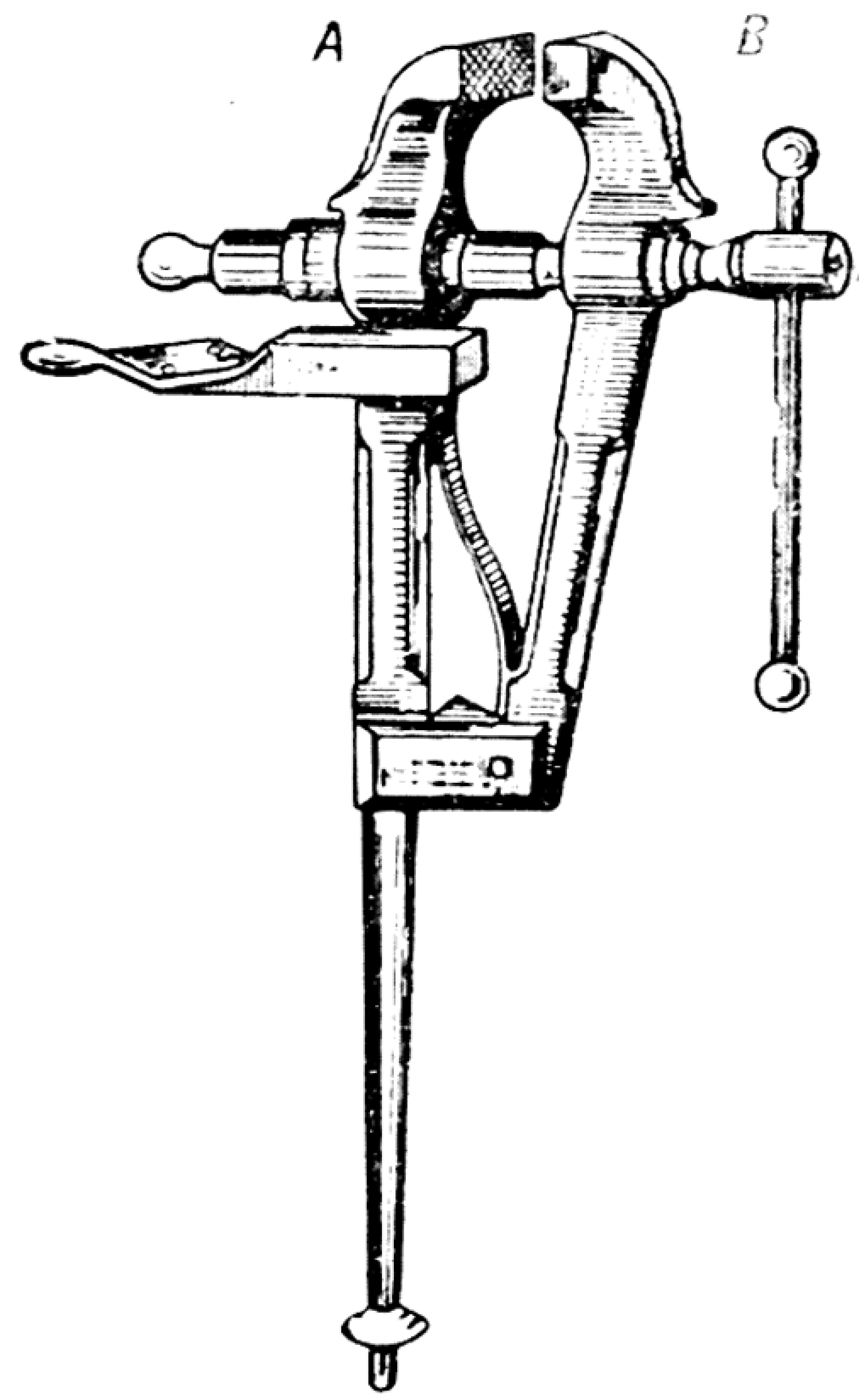


Fig. 3. Bench vise

Vises should always be kept in exemplary order, and always firmly secured to the bench. The vise screw should always be kept oiled, and the knurled jaws—clean.

The piece of work to be chiselled should be firmly clamped in the vise jaws, so that it will not move under the heavy blows of the hammer on the chisel. Hold the chisel at an angle of 30° to 35° to the axis of the vise; your left leg should be in front of your right and the angle between heels—from 40° to 70°.

Always observe the following *fundamental rules* during chiselling opérations:

1. All movements of the hand holding the hammer should be made in the same vertical plane; in this way the blows will always be delivered properly and with greater force, and you will feel less fatigue.

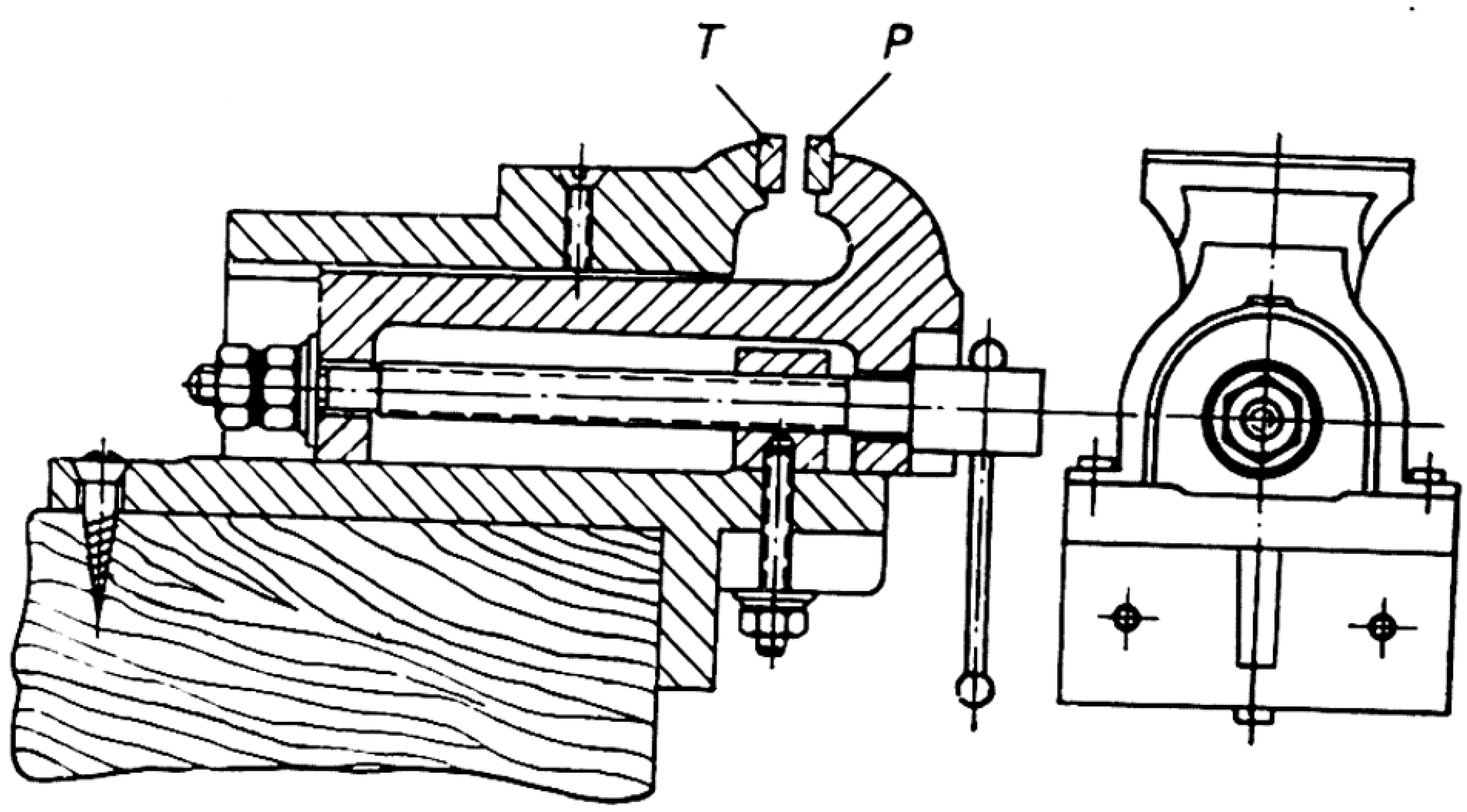


Fig. 4. Parallel vise

2. See that the centre of the hammer head always strike the exact centre of the chisel head. Always keep your eyes on the cutting edge of your chisel, and not on its head.

3. Always hold the hammer by the end of the handle; this increases the force of the blow.

4. When cutting a wide surface, first of all cut a narrow groove with your cape chisel, and then chip away the metal remaining between the grooves.

5. When chipping brittle metals (cast iron and bronze), take the edges off the sides of your work (chamfers) before proceeding to chisel the work, so as to prevent them from crumbling.

6. To speed up the chiselling of soft metals (iron, copper), lubricate your chisels with machine oil or soapy water. Gray cast iron must be chiselled with a dry chisel.

7. To prevent accidents from flying chips, place wire-net guards between the vises, and wear goggles.

8. When grinding chisels, consider the work in hand; the lip angles for chiselling different metals are given in Table 1. Both sides of the cutting edge should be ground flat, straight, and with equal angles.

9. Do not cut chips more than 1.5-2.5 mm thick.

FILING

Comparatively small layers of excess metal are removed by filing; the external surfaces of a piece of work are also finished by filing. Filing is carried out with *files*, which are made of hardened carbon steel containing from 1.1 to 1.2 per cent of carbon; their surfaces are cut (Fig. 5). Files are classified into the following three groups, depending on the spacing of their teeth.

Class 1 includes *bastard files*, for removing layers of metal from 0.5 to 1.0 mm thick, i. e., for rough filing. These files are cut with various tooth spacings, the coarsest (rough) files having from 16 to

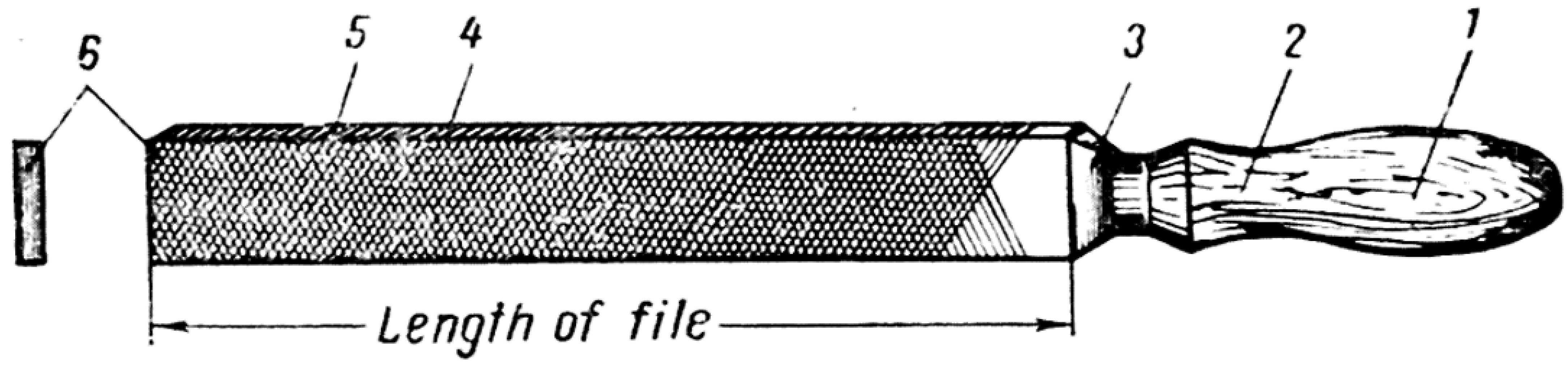


Fig. 5. File:
1) handle; 2) tang; 3) heel; 4) edge; 5) face; 6) end, or nose

20 teeth per inch; medium rough (coarse) files—from 20 to 24 teeth per inch; bastard files—from 24 to 30 teeth per inch; semi-smooth files have from 30 to 40 teeth per inch.

Class 2 includes *smooth files*, which are employed for removing layers of metal up to 0.1 mm in thickness. These files are cut finer, usually with 40 to 60 teeth per inch, and they give a smoother surface to the work.

Class 3 includes files employed for *finish-filing* surfaces.

Files are further designated according to their cross-section: flat files—for filing the various surfaces of work pieces; square files—for filing surfaces, square and rectangular holes in work pieces; three-square, or triangular files—for filing internal angles; round files—or filing rounded recesses and holes; half-round files—for filing concave surfaces.

Files should be selected about 150 to 200 mm longer than the length of the work to be filed; this will ensure the best surface finish after filing.

File handles are generally made of birch or beech, and should be at least 1.5 times as long as the tang of the file.

To file a piece of work, clamp it in a vise, and move the file horizontally backwards and forwards over its surface. In doing so, see that your body is about 200 mm from the vise; stand almost upright, slightly inclined forward and at an angle of approximately 45° to the axis of the vise. Hold the file in both hands, the handle in your

right hand, and the end in your left. During the forward stroke, gradually increase the pressure of your right hand on the file, and lessen that of your left. If the pressure on the file is unchanged, the edges of the work will be filed more than the rest and its surface will be improperly filed, its edges being rounded off.

Files are cut so that the cutting, or filing action takes place only during the forward stroke. Pressure should therefore be exerted on the file only during the forward stroke; when working with the file, the pressure applied should be co-ordinated with the speed of the filing strokes. You will file quicker and better if you move the file slowly with a heavy pressure.

Bastard files are used for *rough filing*; to avoid deep filing strokes on the surface of the work and to ensure greater accuracy, the direction of the strokes should be alternated. When filing, check the surface being filed from time to time with a straight edge or a set-square, by applying their edges in different directions to the surface of the work.

Leave an allowance from 0.1 to 0.2 mm for *finish filing* with a smooth file. When polishing, wrap a piece of emery cloth around a piece of wood, and, after oiling the work with a thin layer of oil, move the piece of wood backwards and forwards over the surface of the work, with a light pressure. To prevent the teeth of files from being clogged up with chips when filing tough metals, such as copper, the file should be rubbed with chalk before commencing work.

Thin, flat work should be filed on a flat bar of wood 25-50 mm thick, to which it should be fastened with thin nails to prevent it shifting during filing. This done, the wooden bar together with the work is clamped in the vise and filed in the usual manner.

When filing the edges of several similar pieces of work, they can be stacked together (three to five pieces) and clamped in the vise for filing.

The *quality of a file* can be checked by striking it against a piece of iron or steel; if it is not cracked, the file will give a clear note, while a cracked file will give a specific dead sound. A good file should be light-gray in colour. If it is dark, the file is either oxidised or not sufficiently hardened.

The teeth should be uniformly cut to an equal depth.

DRILLING HOLES

Holes are drilled with the aid of drills. These are classified as flat and twist drills. *Flat drills* are made single-lipped (Fig. 6) or double-lipped (Fig. 7). Single-lip flat drills are better than double-lip drills; the latter do not drill, but only scrape the metal.

Twist drills (Fig. 8) are more frequently used, as they allow higher drilling speeds, and holes drilled with them are more accurate and have a higher surface finish. When grinding twist drills, care should be taken to see that the length of the cutting edges and their angles are equal, otherwise the diameter of the hole will be greater than that of the drill, or, as is said, the hole will "run out".

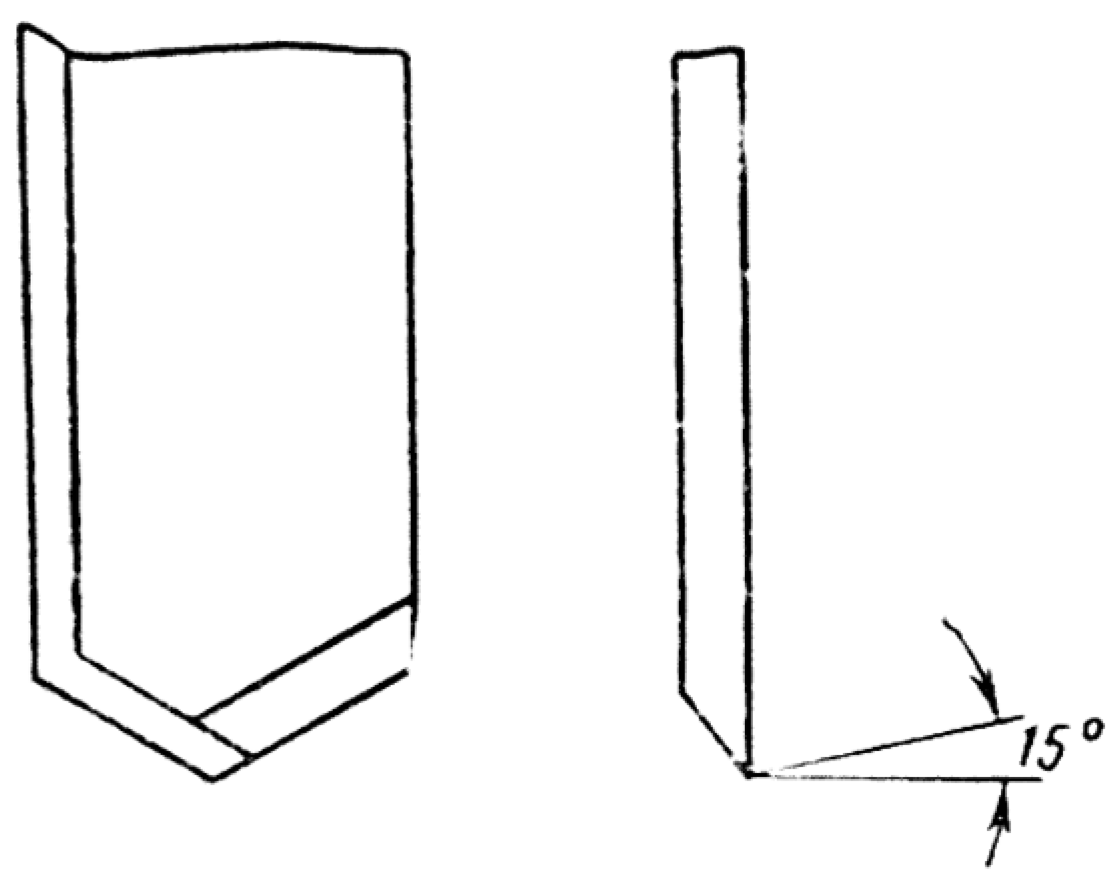


Fig. 6. Single-lip flat drill

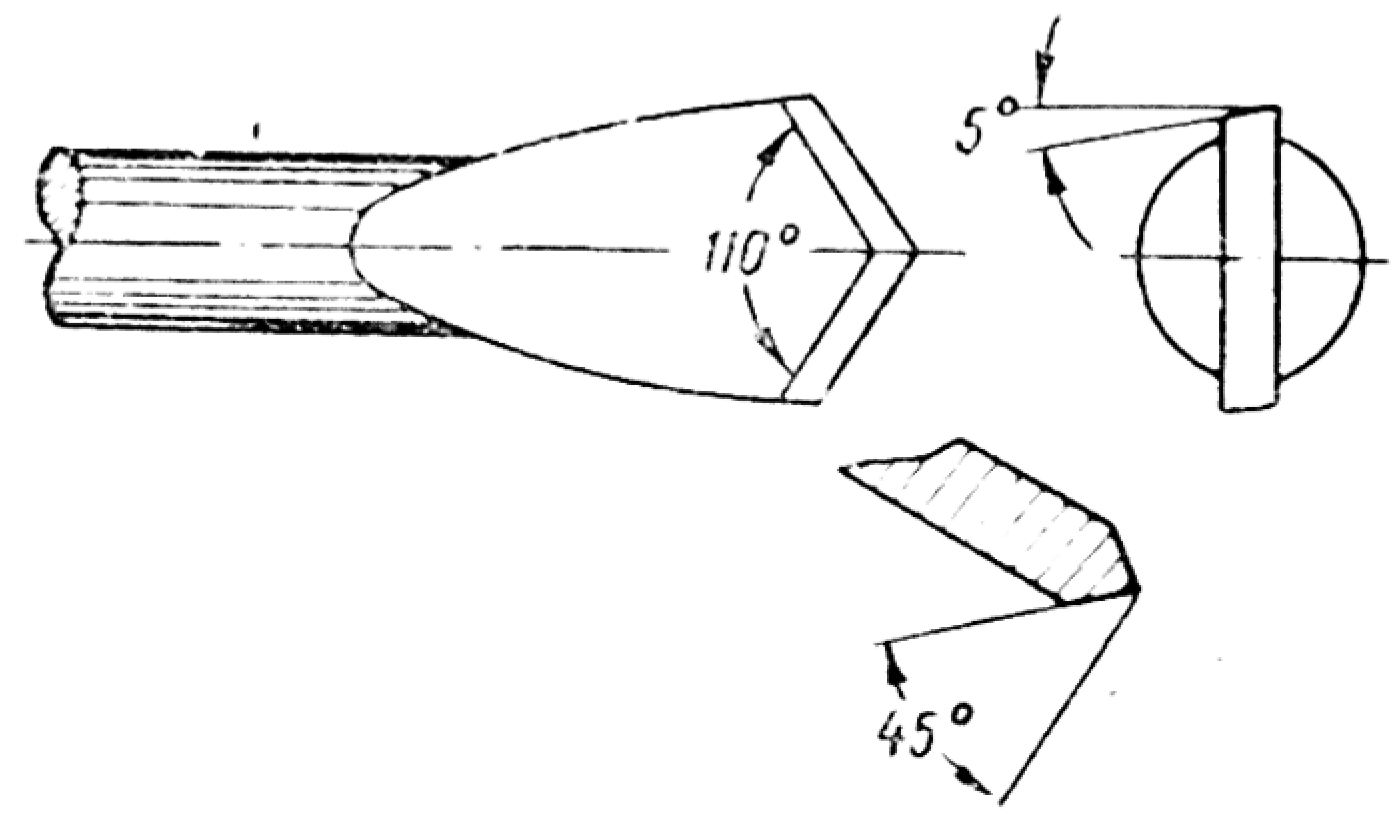


Fig. 7. Double-lip flat drill

Holes can be drilled on special drilling machines, with electric or pneumatic drills or with hand ratchets. Hand-ratchet drills are employed whenever pneumatic or electric drills cannot be used.

The best modern device for drilling operations is the *drilling machine*, which ensures both high productivity and accurate holes.

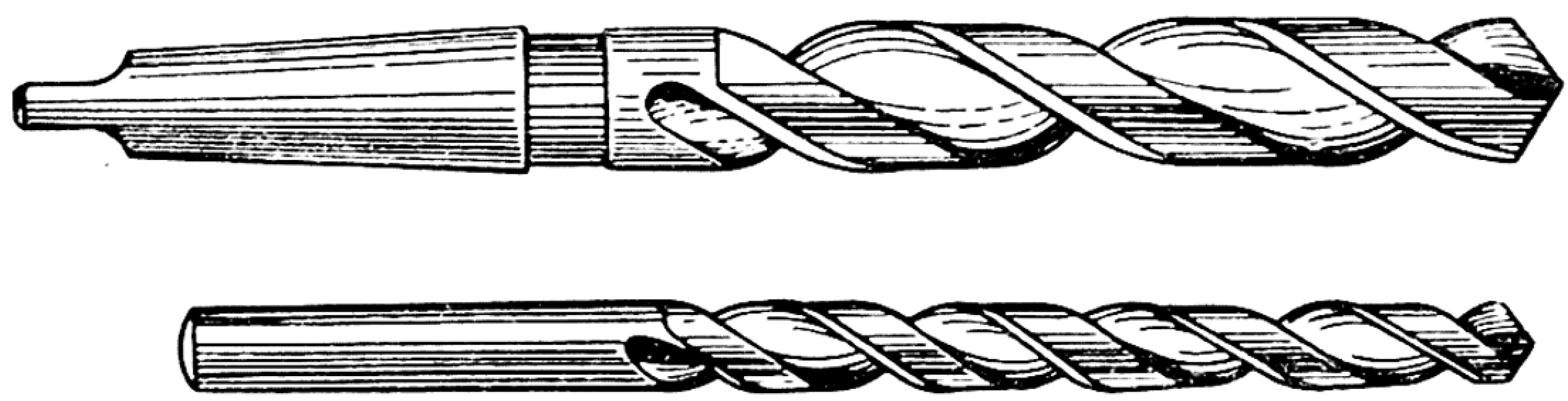


Fig. 8. Twist drills

To drill holes on drilling machines, it is necessary:

1) To secure the drill in the spindle accurately and firmly;

2) To install the work accurately on the machine, i. e., so that the axis of the drill coincides exactly with that of the hole to be drilled;

3) To fasten the work securely on the machine table or in the vise;

4) To reduce the feed of the drill towards the end of the operation, to avoid breaking it;

5) To bear in mind that, at high speeds, the cutting edges of the drill get hot and that they grow blunt quickly at temperatures above

250-300° C; for this reason drills should be cooled with some kind of liquid in order to increase their life.

The most commonly used coolant (emulsion) is a solution of soda in water, or an emulsion prepared by adding a small quantity of soap dissolved in oil to water. Emulsions possess lubricating properties, and thus reduce the consumption of power during drilling operations. Moreover, the surface finish of the holes is better, and the life of the cutting edges is increased by the use of emulsions.

CUTTING THREADS

There are several types of threads, known as metric, inch, pipe, square, trapezoidal, buttress and round threads. Metric, inch, and pipe threads can be cut either by hand or on machines, while square, trapezoidal, buttress and round threads can be cut only on lathes.

The hand cutting of threads is done with ordinary machinists' taps and dies. *Taps* are used for cutting internal threads as, for example, threads in nuts; *dies* are employed for cutting external

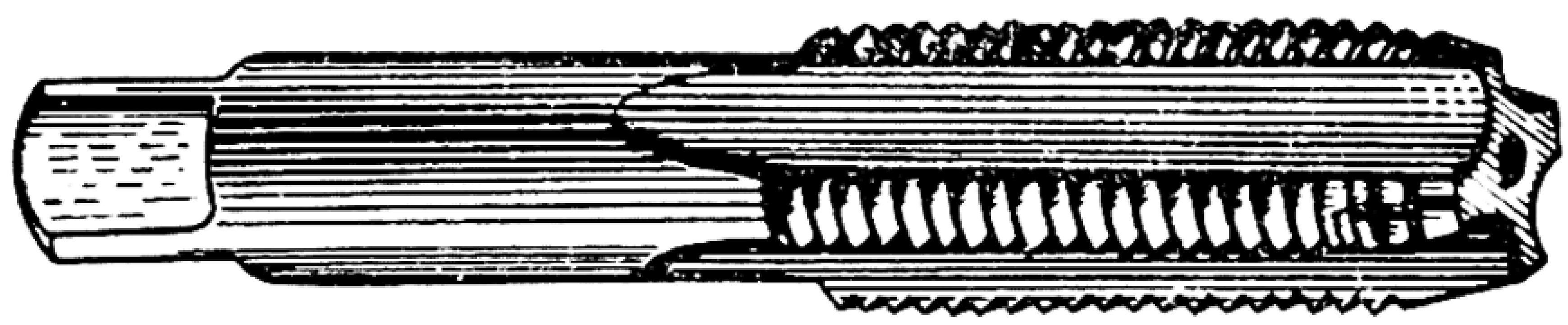


Fig. 9. Tap

threads, as on bolts. Taps are made of grades Y10 and Y12 carbon steel, in sets of three; and threads are cut consecutively with the first, second and third, or finish taps (Fig. 9). A tap consists of its working part and its shank; the working part is made in the form of a screw with grooves; the grooves form the cutting edges and serve as an exit for the chips. The end of the shank is square to fit the tap wrench.

Dies are generally circular in shape (Fig. 10); they have cutting edges *1* and openings *2*. When cutting threads, they are secured in die-stocks.

When cutting threads the tap or die must be placed absolutely vertically in, or over, the work. To ensure easier cutting and to speed up the crushing of the chips, the tool is given a complete turn in one direction, and a half turn in the opposite direction; this process must be repeated until the thread is completely cut. Lubricants are used to reduce the friction between the tap or die and the metal being threaded, and to ensure a smoother and better finished thread surface.

Among the lubricants used are: natural linseed oil, emulsions, mineral machine oils and, for threading aluminium—kerosene, while turpentine is used when threading copper. Care must always be taken

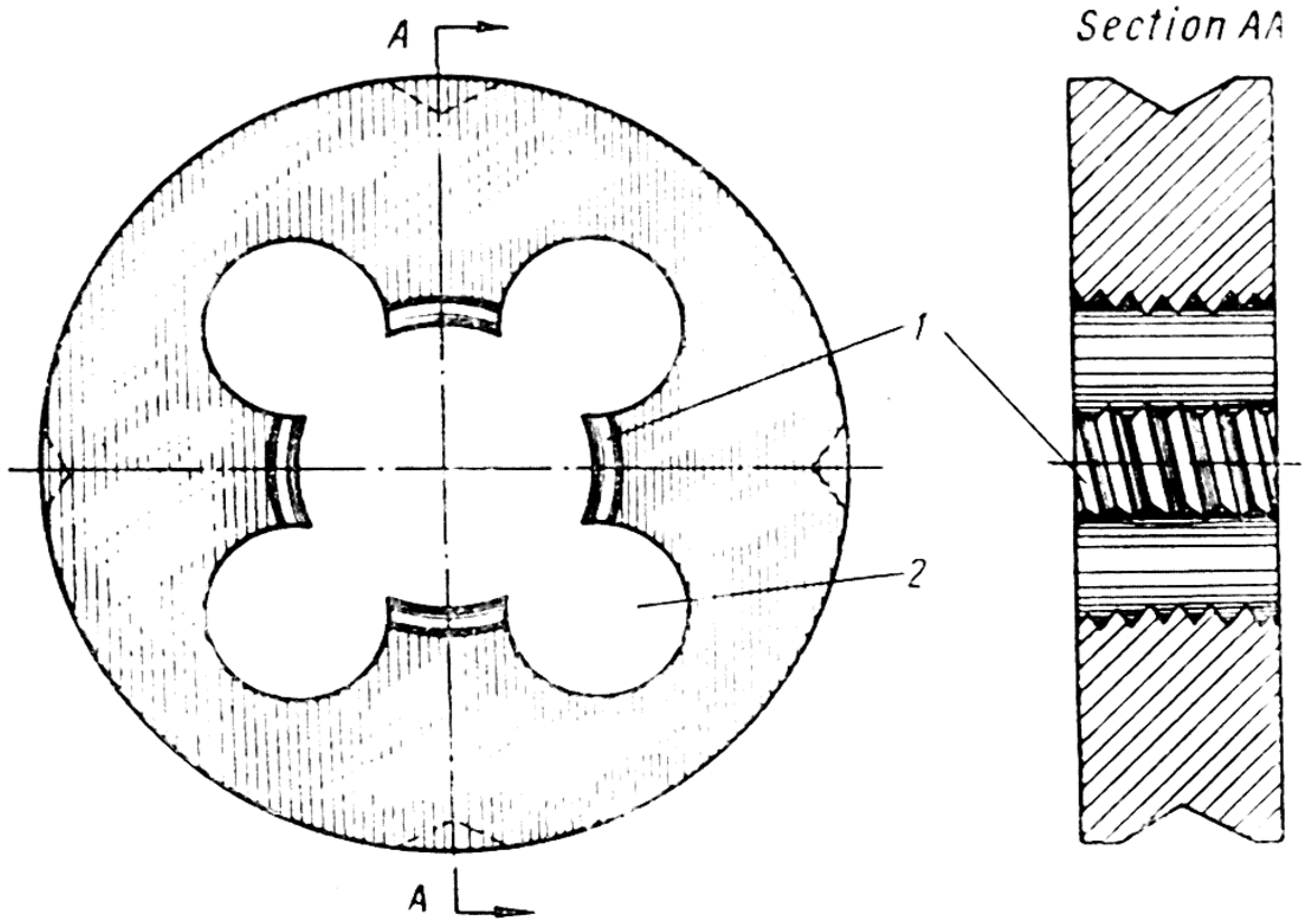


Fig. 10. Threading die

not to choke the tap grooves with chips. When threading with the second and third taps, the tap wrench should be fitted over the shank of the tap only after the tap has been inserted in the thread by hand.

MEASURING INSTRUMENTS

An ordinary wooden or steel folding ruler or a *scale* can be employed for taking straight measurements to an accuracy of 1 mm. Scales are generally graduated in millimetres or inches. To convert inches into millimetres multiply the number of inches by 25.4 (1 inch = 25.4 mm). When measuring with a scale or ruler, place it directly on the work so that the end of the ruler coincides exactly with the end of the work from which you are reading the measurements. Fig. 11 shows a scale graduated in inches and millimetres, half its natural size.

Vernier calipers (Fig. 12) are employed for measuring work to an accuracy of 0.1 mm. A vernier caliper consists of a steel ruler *A*, with jaws *B* and *D* attached to one of its ends, and of a freely moving

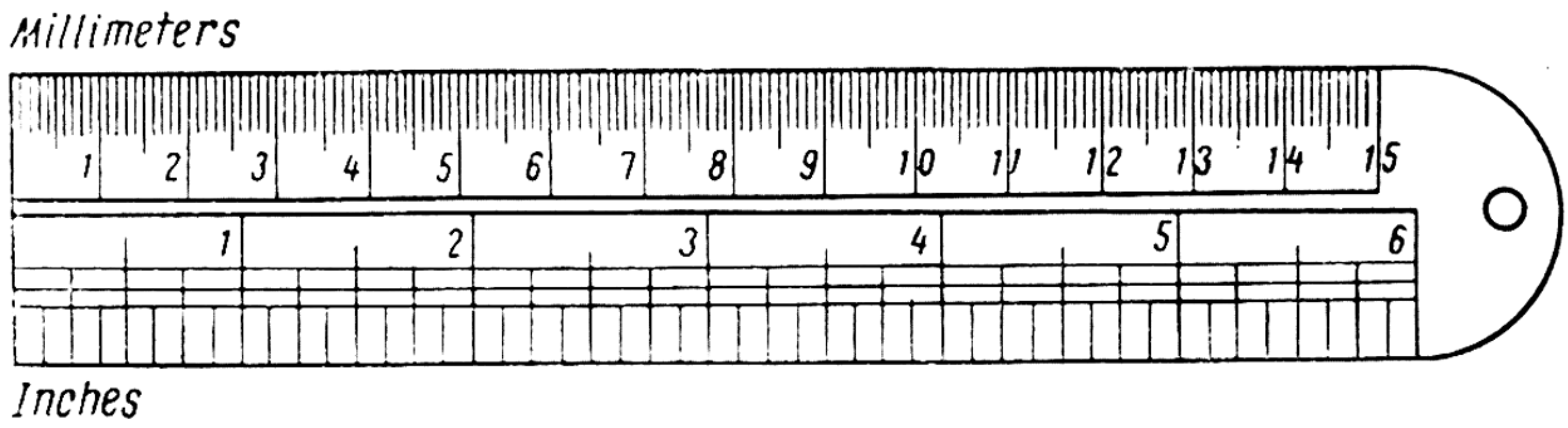


Fig. 11. Scale, or ruler

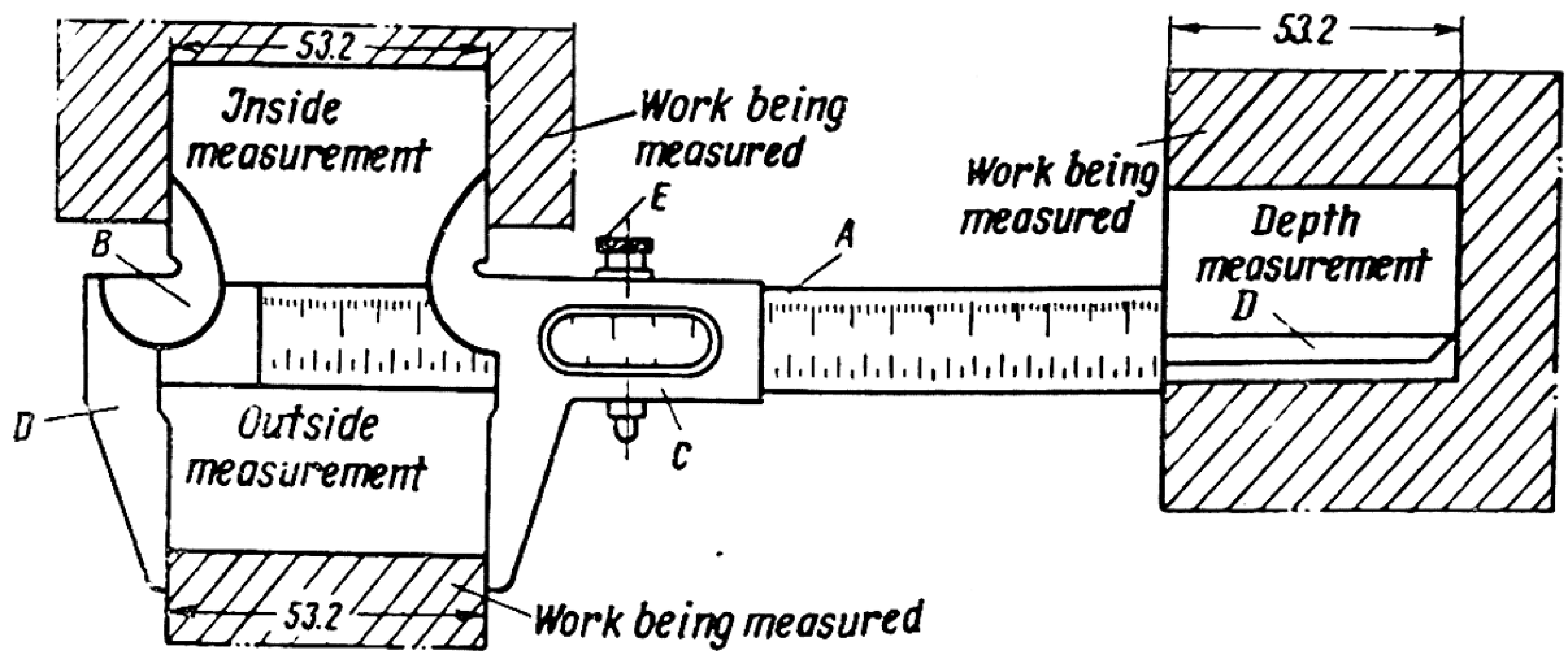


Fig. 12. Vernier caliper and scheme of its operation

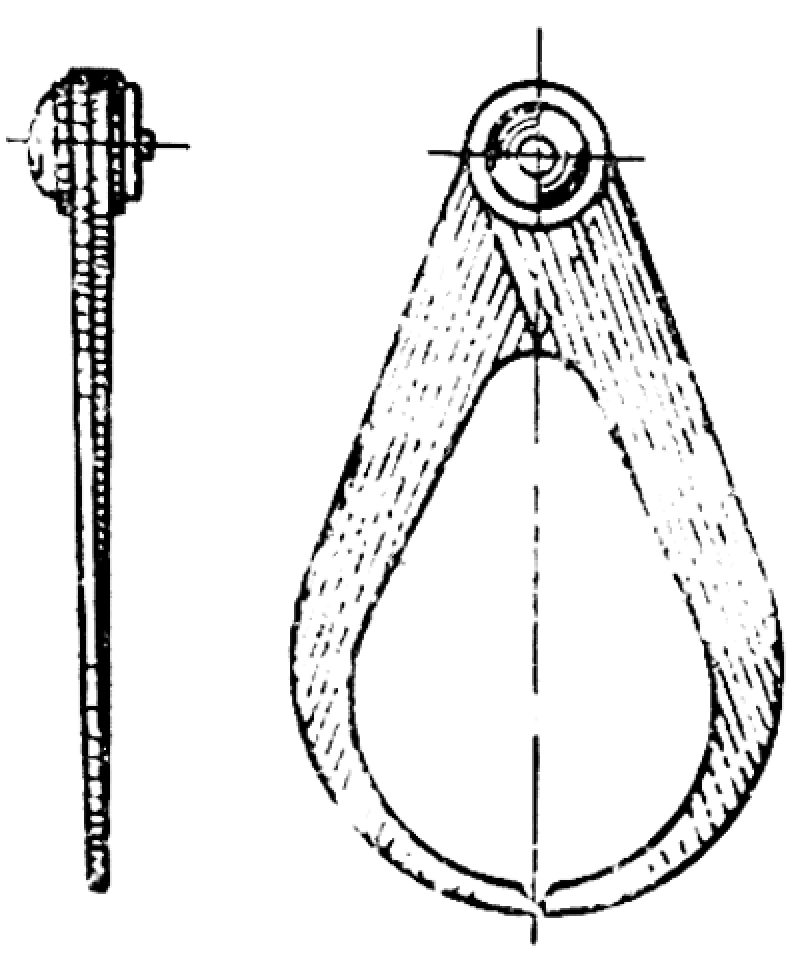


Fig. 13. Outside caliper

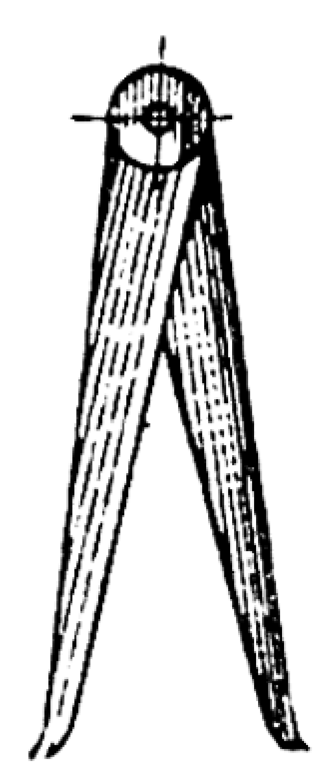


Fig. 14. Inside caliper

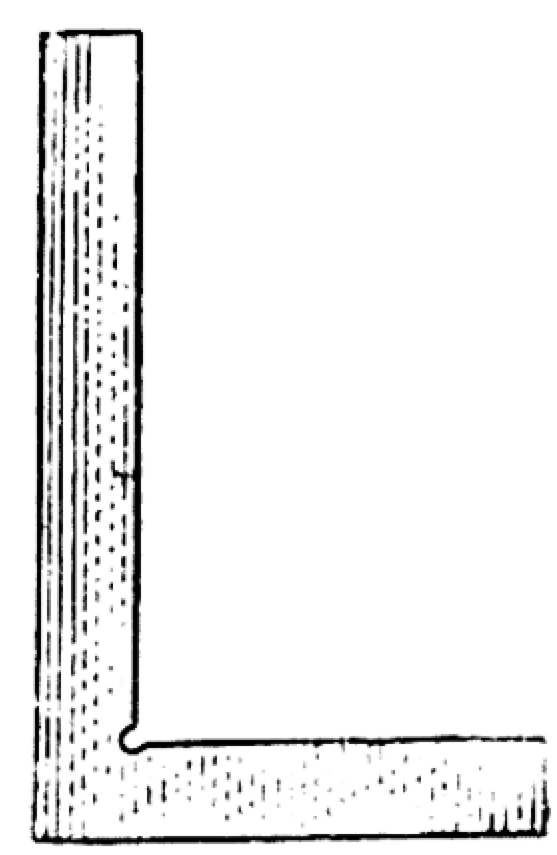


Fig. 15. Trysquare

slide C with similar jaws. The slide can be fixed in any position on the rule with the aid of setscrew E. Rod F attached to the opposite end of the rule is for taking depth measurements.

When transferring measurements from the scale to the work, or from the work to the scale, the *outside caliper* (Fig. 13) is used for measuring outside dimensions, and the *inside caliper* (Fig. 14) for measuring the inside diameters of holes. *Trysquares* (Fig. 15) are employed for checking angles between surfaces.

CHAPTER II

INTRODUCTION TO FORGING PRACTICE

FORGING OPERATIONS

Forging is the hot working of metals performed by means of hammer blows or under the pressure of a press. Various kinds of machine parts, of different shapes and sizes, are made by forging or stamping operations.

Forging enhances the mechanical properties of metal and improves its structure. For this reason, as has already been said, the more important parts of machines, such as shafts, cranks, drums, etc., are manufactured either by hammer forging or by hot stamping (die-forging).

Forging operations can be hand and machine (or mechanical) operations. *Hand forging* is carried out on anvils with the aid of hand forging tools. *Machine forging* is done under forge hammers or presses. As a rule, in machine forging, heavy forgings are produced in presses, and lighter ones by hammers.

Depending on the methods of the production of forgings, forging processes are classified as *hammer* and *die-forging* (stampings, or semi-stampings).

In hammer forging, the shape of the metal is changed by pressing it between the dies of a hammer or a press. In doing this, the flow of the metal (i. e., the changing of its dimensions and shape) is controlled with the aid of various blacksmith's tools.

In drop forging or stamping, the flow of metal is limited by the surfaces of the recesses in the dies, in which the metal takes its predetermined shape and dimensions. Every part manufactured by the drop-forging process requires a separate die or set of dies.

Forgings which have to undergo subsequent machining are called *blanks*. Those which do not require any further machining are known as *finished* forgings.

BRIEF INFORMATION ABOUT STEEL AND ITS PROPERTIES

The chief material with which blacksmiths deal in the process of their work is steel, which is very malleable. *Steel* is an alloy of iron and carbon, together with certain other elements. The carbon content in steel does not exceed 1.7 per cent.

The properties of steel and its forging conditions vary depending on content of various alloying elements. For instance, the grade of steel used for making forgings always determines: 1) the time and temperature required for pre-heating the steel; 2) the heating conditions; 3) the number of heats (number of charges in and out of the furnace) during the forging operations; 4) the capacity of the forging equipment; 5) the methods of making the forgings; 6) the conditions for cooling the forgings; 7) the heat-treatment conditions.

Steel possesses definite properties, which can be classified as physical, mechanical and technological (engineering). Table 2 gives the conventional symbols employed in the U.S.S.R. for denoting the various elements of which steel is composed.

Table 2

Element	International chemical symbol	Symbol used in U.S.S.R. standards steel grade indexes	Element	International chemical symbol	Symbol used in U.S.S.R. standards steel grade indexes
Carbon	C	—	Molybdenum	Mo	М
Manganese	Mn	Г	Tungsten	W	В
Silicon	Si	С	Vanadium	V	Ф
Phosphorus	P	—	Aluminium	Al	Ю
Sulphur	S	—	Titanium	Ti	Т
Chromium	Cr	Х	Copper	Cu	—
Nickel	Ni	Н			

The main *physical properties* of steel are: specific gravity, thermal capacity, melting temperature and thermal conductivity.

Of the physical properties of steel, the most important for forging operations are its thermal capacity and thermal conductivity.

Thermal capacity is that quantity of heat (in large calories) required to raise the temperature of 1 kilogram of matter one degree Centigrade. The thermal capacity of steel varies with the content of alloying elements.

Specific gravity is the weight of a unit volume of a substance (i. e., in this case, the weight of 1 cubic metre or 1 cubic centimetre of steel). The specific gravity of steel also varies with its composition, but only slightly. In forging practice the practical average specific gravity of steel can, for calculation purposes, be taken as being 7.85 (the weight of 1 cubic metre of steel equals 7.85 tons).

Thermal conductivity is the ability of a substance to transfer heat from one, hotter part to another part of the substance at a lower

temperature. For instance, if a metal rod is heated at one end, the heat will be transferred to the other, colder end of the rod, as a result of its thermal conductivity. Another example of thermal conductivity can be seen in the transfer of heat from the surface to the central portion of an ingot or billot being heated in a furnace.

Of the *mechanical properties* of steel, the most important are:

1) *Tensile strength*—i. e., its ability to withstand rupture under the influence of external forces; the stronger the steel the greater the load it can withstand;

2) *Hardness*—the property of steel to withstand the impression of foreign bodies; the hardness of steel is determined by special machines (the Brinnell, Rockwell and other hardness testing machines) by pressing a hardened steel ball or a diamond cone into a test specimen; the greater the indenture of the ball or cone into the specimen, and the greater the impression remaining on its surface, the softer the steel is;

3) *Plasticity*—the ability of steel to change its shape without destruction under the influence of external forces, and to retain its shape on the cessation of the action of these forces;

4) *Ductility*—the ability of steel to change its shape without destruction under considerable impact loads;

5) *Malleability*—the ability of steel to be worked under pressure (forging, rolling, drawing, etc.);

6) *Elasticity*—the ability of steel to change its shape without destruction under the influence of external forces and to return to its original shape on the cessation of the action of these forces.

The chief technological, or engineering, properties of steel include:

1) *Weldability*. When heated, steel gradually softens and at a temperature of 1300-1400°C becomes pasty. If two pieces of steel, heated to a pasty condition, are placed together and pressed (under a press or hammer), they will unite to form a single piece or, as it is termed, they will be welded together;

2) *Hardenability*. Steel heated to a temperature of 750-900°C (depending upon its composition) and rapidly cooled in water or in oil will become harder and more brittle. This process, which is accompanied by a change in its structure, is called hardening.

The greater the carbon content of a steel, the better it can be hardened. Steel containing up to 0.15 per cent of carbon will not harden while, on the other hand, steel containing over 0.5 per cent of carbon, hardens extremely well.

The various elements entering into the composition of steel influence its properties in the following manner:

Carbon (C). The hardness, tensile strength and hardenability of steel increase with its carbon content, while its malleability and

thermal conductivity decrease. The greater the carbon content in the steel, the slower must it be heated. Steel containing up to 1.4 per cent of carbon possesses good forging and rolling properties.

Silicon (Si) increases the tensile strength and elasticity of steel, but lowers its ductility and weldability. Structural steels usually contain 0.2-0.4 per cent of silicon. Silicon has no appreciable influence on the malleability of steel.

Manganese (Mn). Ordinary carbon steels contain from 0.2 to 1 per cent, and special steels—up to 14 per cent of manganese. Manganese increases the impact and tensile strengths of steel, lowers its wear and decreases the harmful effect of sulphur. The thermal conductivity and weldability of steel fall with an increase in the manganese content. Manganese tends to increase the susceptibility of steel to overheating and the occurrence of cracks; the greater the manganese content, the slower the steel must be heated; to avoid overheating manganese steels, it is necessary to control the temperature of heating and soaking at high temperatures carefully. Properly heated manganese steel stock and billets lend themselves well to forging.

Nickel (Ni) increases the plasticity, tensile strength and ductility of steel. It does not influence its malleability; however, on heating nickel steels, scale firmly adheres to the surface and there is a danger that this scale may be forged into the steel, thereby lowering its mechanical properties.

Chromium (Cr) increases the hardness, tensile strength and elasticity of steel; at the same time, it lowers its ductility and thermal conductivity. The structure of a cast ingot of chromium steel is difficult to break down during forging, and chromium steel forgings must be subjected to considerable working at high temperature in order to obtain a fine-grain structure. Chromium steels can be satisfactorily forged at high temperatures (1500-850°C), but at temperatures below 850°C, their surface hardness sharply increases, with the accompanying danger of the formation of cracks.

Molybdenum (Mo) is usually added to steel together with nickel and chromium. Usually the molybdenum content in various grades of steel does not exceed 0.45 and rarely reaches 1 per cent. When present together with chromium and nickel, molybdenum increases the tensile strength and ductility of steel, but lowers its thermal conductivity. The greater the molybdenum content, the slower must the steel be heated, as the presence of molybdenum greatly increases its susceptibility to overheating. Molybdenum steels require intensive forging on more powerful presses or hammers than those employed for forging carbon steels. Molybdenum steel forgings must be cooled slowly, strictly according to the specifications of the technological process, as they are liable to air hardening, and have a tendency to crack.

Vanadium (V). In engineering steels the vanadium content does not usually exceed 0.3 per cent, and rarely exceeds 1 per cent. Vanadium increases the tensile strength and elasticity of steel, and facilitates the formation of a fine-grain structure in ingots. It also improves its forgeability and prevents overheating.

Tungsten (W) increases the hardness and tensile strength of steel, slightly lowers its ductility and reduces its thermal conductivity. When forged at low temperatures, tungsten steels tend to crack. These steels require a lower rate of heating, and a higher forging temperature, than carbon steels.

Sulphur (S). The presence of sulphur, though a harmful ingredient of steel, is unavoidable, as it is retained in the steel during its smelting. The sulphur content should be kept as low as possible. Its content in steels intended for the manufacture of specially important parts should never exceed 0.02-0.03 per cent, and in ordinary steels —from 0.045 to 0.055 per cent. A higher sulphur content will lead to hot-shortness. Such a steel, on being heated to a red heat, will become brittle and will crack and break up during forging. At ordinary temperatures sulphur lowers the tensile strength of steel.

Phosphorus (P), as distinguished from sulphur, imparts cold-shortness to steel, that is, causes it to become brittle at normal temperature. The maximum phosphorus content in steel for important parts should never exceed 0.03-0.04 per cent. The greater the carbon content in the steel, the greater the permissible phosphorus content. Cold-shortness of steel frequently occurs when straightening and bending work during cold weather in unheated premises.

CLASSIFICATION OF STEELS

Steels are classified according to their manufacturing process, chemical analysis, and application.

Depending on their *manufacturing process*, steels are classified as Bessemer, Thomas, basic open-hearth, acid open-hearth, electric and crucible steels. *Bessemer steel* is smelted by blowing compressed air through molten pig-iron in a special converter-retort. In this converter the molten metal is further heated by the heat evolved during the burning-out (oxidation) of the silicon and other elements contained in the pig-iron.

Pig-iron used for manufacturing Bessemer steel must have a low phosphorus and sulphur content. If, however, ordinary grades of pig-iron are used for manufacturing Bessemer steel, the latter will have sulphur and phosphorus content of up to 0.06 and 0.08 per cent respectively, which limits its application in the manufacture of important parts.

Thomas steel, like Bessemer steel, is manufactured in converters, with the difference that in the Thomas process, the converters are lined with dolomite brick. The employment of such a lining enables high-phosphoros pig-irons to be processed in converters, the resulting steel having a lower phosphorus content than Bessemer steel.

Basic open-hearth steel is manufactured in open-hearth furnaces, the hearths of which are lined with magnesite (basic) brick. In this process, the furnace is charged with pig-iron and steel scrap. Basic open-hearth steel is employed for the manufacture of important parts.

Acid open-hearth steel is smelted in similar open-hearth furnaces as used for basic open-hearth steel; in this case, however, the furnace hearths are lined with dinas (acid) brick fused on to quartz sand. The charge in this process consists of pig-iron, iron scrap and steel scrap. The phosphorus content of the charge should not exceed 0.03 per cent, as in this process all the phosphorus is retained in the steel. When high-quality charging materials are used high-grade steel can be obtained in acid open-hearth furnaces.

Electric steel is smelted in electric arc or induction furnaces; in this process the furnace hearths may be either basic or acid. Electric steel is of high quality and is employed for the manufacture of more important parts.

Crucible steel is manufactured in refractory crucibles; the charge for steel made by this process must be of particularly high quality. Crucible steel is rarely used owing to its high cost; electric steel is usually employed in its stead.

As regards chemical composition, steels are divided into carbon and alloy steels. *Carbon steels* contain iron and carbon, with small amount of constant admixtures: up to 1 per cent of manganese, up to 0.5 per cent of silicon, and a maximum of 0.05 per cent each of sulphur and phosphorus. The fundamental element which determines the mechanical properties of steel is carbon. The carbon content depends on the use to which the steel is to be put, and can vary over a wide range, from the very low figure of 0.02 to 0.03 per cent in iron to 1.2-2.4 per cent in heat resistant and tool steels.

Alloy steels are steel alloys containing special alloying elements such as nickel, chromium, molybdenum, tungsten, vanadium, cobalt, manganese and others; the alloying element determines the name of the steel. Thus, for instance, if it is chromium, nickel, or both, the steel will be known as chromium, nickel, or chromium-nickel steel.

As regards application, steels are classified as: structural, tool, and special steels. Structural steels in turn are subdivided into carbon structural steels and alloy structural steels.

Structural carbon steels are employed for the manufacture of less important parts, and alloy structural steels for more important parts.

Tool steels are employed for the manufacture of various tools—cutting, measuring, dies and other tools and instruments. They are divided into two groups—carbon and alloy tool steels.

Special steels include heat resistant, refractory, stainless, acid-resistant and other steels.

GRADES OF STEELS

There are many grades of steel in use. In the Soviet Union the chemical compositions of the main grades of steel has been determined by special government *standards*, called GOST (ГОСТ) for short, from the initial letters of the Russian words: Gosudarstvenny Obshchesoyuzny Standart (All-Union State Standard).

Structural carbon steels are classified as ordinary quality or high-grade structural carbon steels, the latter having a lower phosphorus and sulphur content than the former. U.S.S.R. Standards specify eight grades of ordinary quality carbon structural steels; each grade has its own symbol, i. e.: Ст. 0; Ст. 1; Ст. 2; Ст. 3; Ст. 4; Ст. 5; Ст. 6 and Ст. 7. The figures in these symbols are conventional and have no direct relation to the carbon content; however, the higher the number, the greater the carbon content in the steel and therefore the harder it is.

The different grades of *high-grade structural steels* with a normal manganese content are denoted by two figures only: grades 20; 25; 30; 35; 40; 45; 50; 55; 60; 65; 70; 75; 80 and 85. The figures in the grade symbols of these steels denote the carbon content in hundredths of one per cent. Thus the carbon content of grade 40 steel will be 0.40 per cent (or, if we indicate the tolerances, from 0.35 to 0.40 per cent). The grade symbols of structural steels with an increased manganese content have the letter Г, sometimes accompanied by a figure. The figure following the letter indicates the manganese content of the steel in per cent. Thus grade 60Г2 steel has 0.6 per cent of carbon and approximately 2 per cent of manganese.

U.S.S.R. Standards provide for eight grades of high-grade carbon steel: У7; У8; У8Г; У9; У10; У10Г; У12 and У13, and eight grades of high-grade carbon *tool steel*: У7А; У8А; У8ГА; У9А; У10А; У10ГА; У12А and У13А. The letter У denotes carbon steel; the figures in these symbols denote the tenths of one per cent of carbon in the steel. Thus, grade У8 steel has a carbon content of 0.8 per cent (or, if we wish to indicate the tolerance, from 0.75 to 0.85 per cent). Grade У10 steel has a carbon content of approximately 1.0 per cent. etc.

The letter A denotes high-grade steel which differs from ordinary grade steel in its lower sulphur and phosphorus content. The letter Г in the symbol of certain grades of steel indicates an increased manganese content.

Depending on their chemical composition and mechanical properties, structural and alloy steels are further classified as high-grade and extra high-grade steels. *Extra high-grade steels*, which are distinguished from high-grade steels by their low sulphur and phosphorus content, are indicated by the prefix *A*. The symbol for any grade of structural alloy steel consists of two figures, denoting the hundredths of one per cent of carbon contained in the steel, followed by letters indicating the alloying element or elements. Thus, 15X is the symbol for a grade of chromium-alloy steel having a carbon content of 0.15 per cent; 40XH indicates a grade of chromium-nickel steel having a carbon content of 0.40 per cent. If the content of the alloying element in a given grade of steel is above 1 per cent, its approximate percentage is indicated in the symbol by a figure after the corresponding letters. Thus, 20XH3A denotes an extra high-grade chromium-nickel steel containing 0.20 per cent of carbon, about 1 per cent of chromium and about 3 per cent of nickel.

The grades of alloy tool steel are indicated by figures denoting the tenths of one per cent of carbon, followed by letters indicating the alloying elements contained in the steel. The significance of these letters is the same as those described above. If the carbon content is equal to, or more than 1 per cent, no figures are placed in front of the symbol. Figures placed after the letters denote the approximate content of the alloying element in per cent. The absence of figures in the symbols for these grades of steel is no indication that the content of the corresponding alloying element equals 1 per cent. Thus, X12 is the symbol for a grade of a chromium tool steel containing 12 per cent of chromium and more than 1 per cent (actually, from 1.45 to 2.3 per cent) of carbon; 3XB8 is the symbol for a chromium-tungsten tool steel containing 0.3 per cent of carbon, up to 1 per cent of chromium, and 8 per cent of tungsten.

THE STRUCTURE OF STEEL

All metals, including steel, consist of exceedingly minute particles called *grains*. The grains of a metal can be observed on the surface of its fracture. It can be much better observed on a microsection prepared by cutting out, polishing and etching a small specimen of the metal. The microscope enables us to see clearly that metals really do consist of grains. The way the grains are located in the metal in question is called its grain structure. Grains can differ from each other in size and shape. In one piece of metal the grains may be large,

in another smaller, in a third—of various sizes (mixed), while in a fourth specimen they can be orientated in a definite direction, etc., etc. (Fig. 16).

The size and shape of the grains of any metal are not constant, but vary, depending on the heat and mechanical treatment to which the metal has been subjected. In cast metals, the grains are nearly always large (coarse), while in forged metals they are much finer.

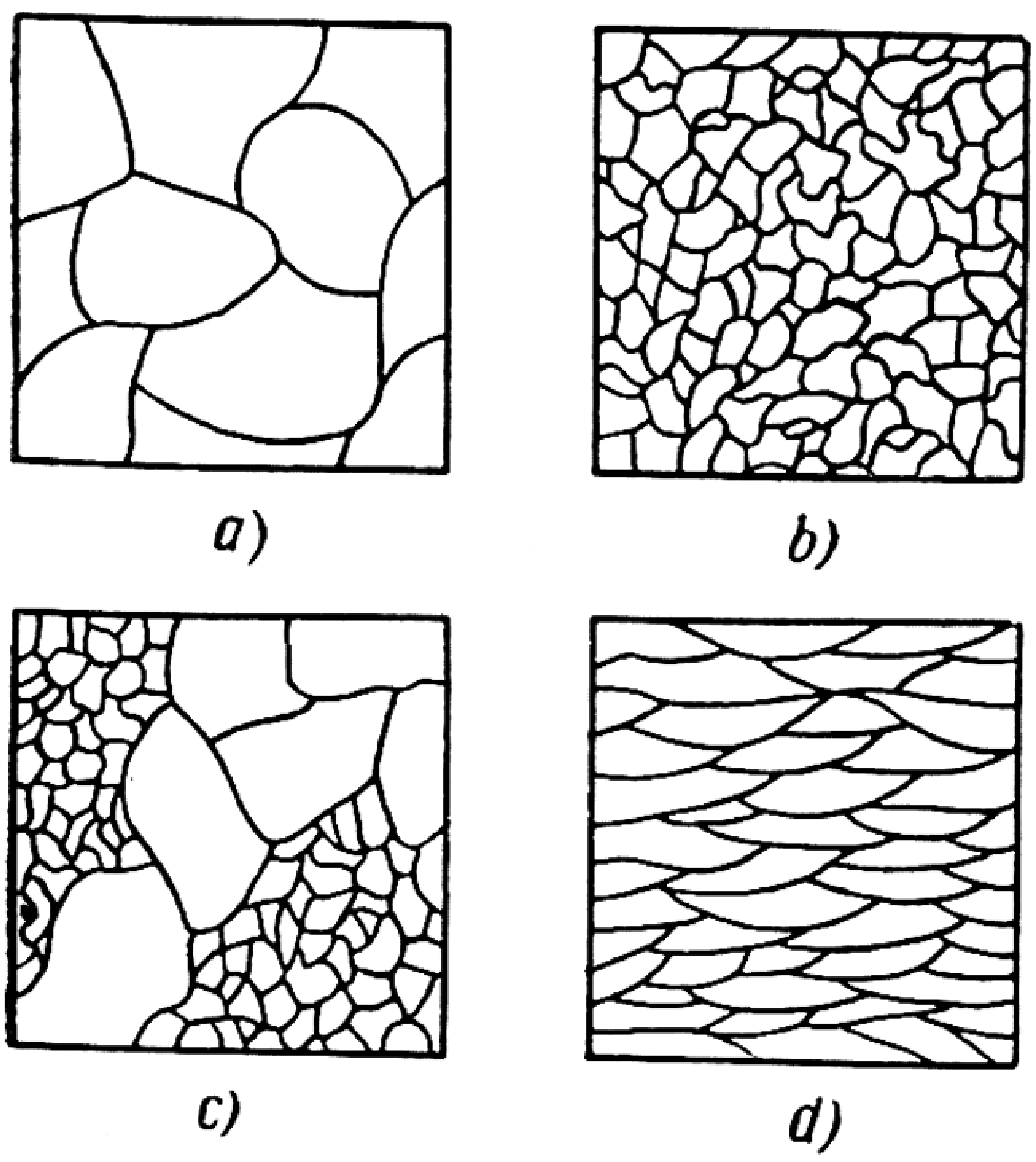


Fig. 16. Types of grain in the structure of a metal:

a) coarse grains; b) fine grains; c) non-homogeneous grains; d) grains orientated in one direction

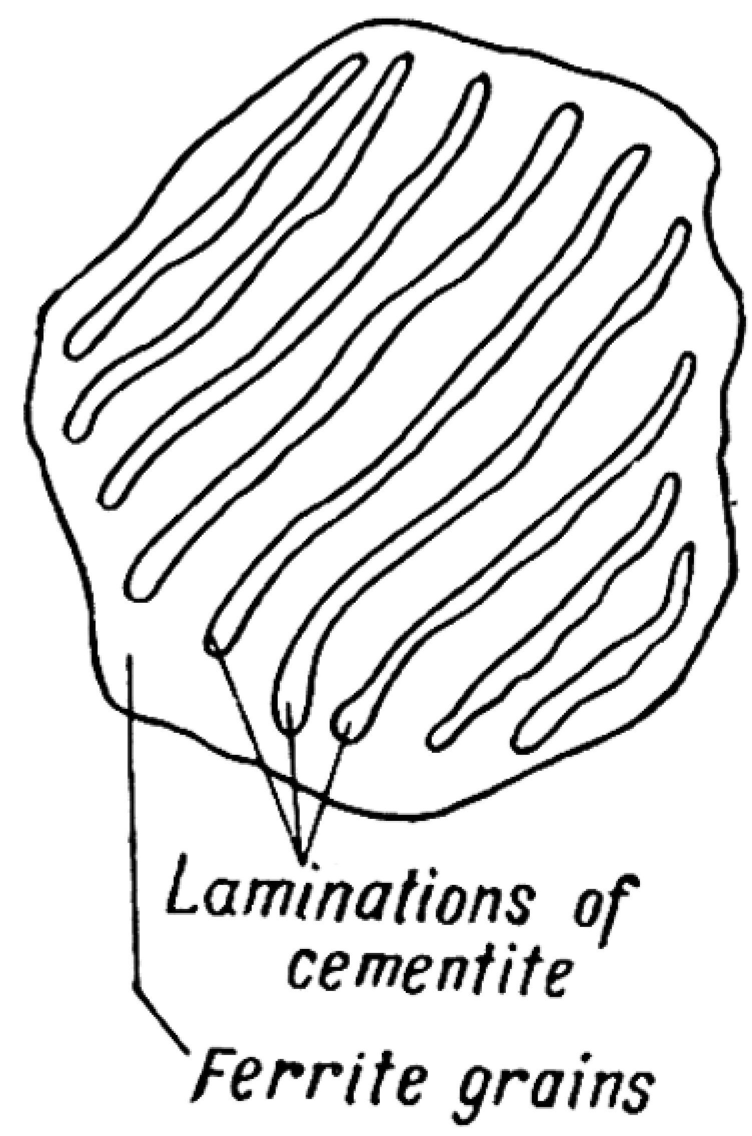


Fig. 17. Scheme of the structure of a pearlite grain

In the process of rolling or forging, the grains are drawn out in a direction parallel to the rolling or forging, and at the same time are compressed in a direction transverse the rolling or forging.

At temperatures not exceeding 720°C, carbon steel consists of grains called *ferrite*, and grains of *cementite*, i. e., iron carbide, which is a chemical compound of iron and carbon, having the chemical formula Fe_3C. But, in addition to these simple grains of ferrite and of cementite, the structure of steel also contains combined (complex) grains consisting of ferrite grains enveloping minute particles of cementite in the form of long, narrow plates. These combined grains are called *pearlite*. In Fig. 17 a grain of pearlite is shown schematically.

From this description of pearlite it is seen that its grains are by no means homogeneous, but consist of a mechanical mixture of ferrite and cementite. A distinguishing feature of this mechanical mixture

is that the proportion of ferrite and cementite in pearlite is absolutely constant. Pearlite contains 86.5 per cent of ferrite and 13.5 per cent of cementite. If this proportion is calculated in terms of carbon content, knowing the carbon content of cementite (6.7 per cent) it can be established that pearlite contains 0.9 per cent of carbon (0.83 per cent according to the latest determinations).

Thus at temperatures not exceeding 720°C there can be only three types of grain in annealed carbon steels: ferrite, cementite and pearlite.

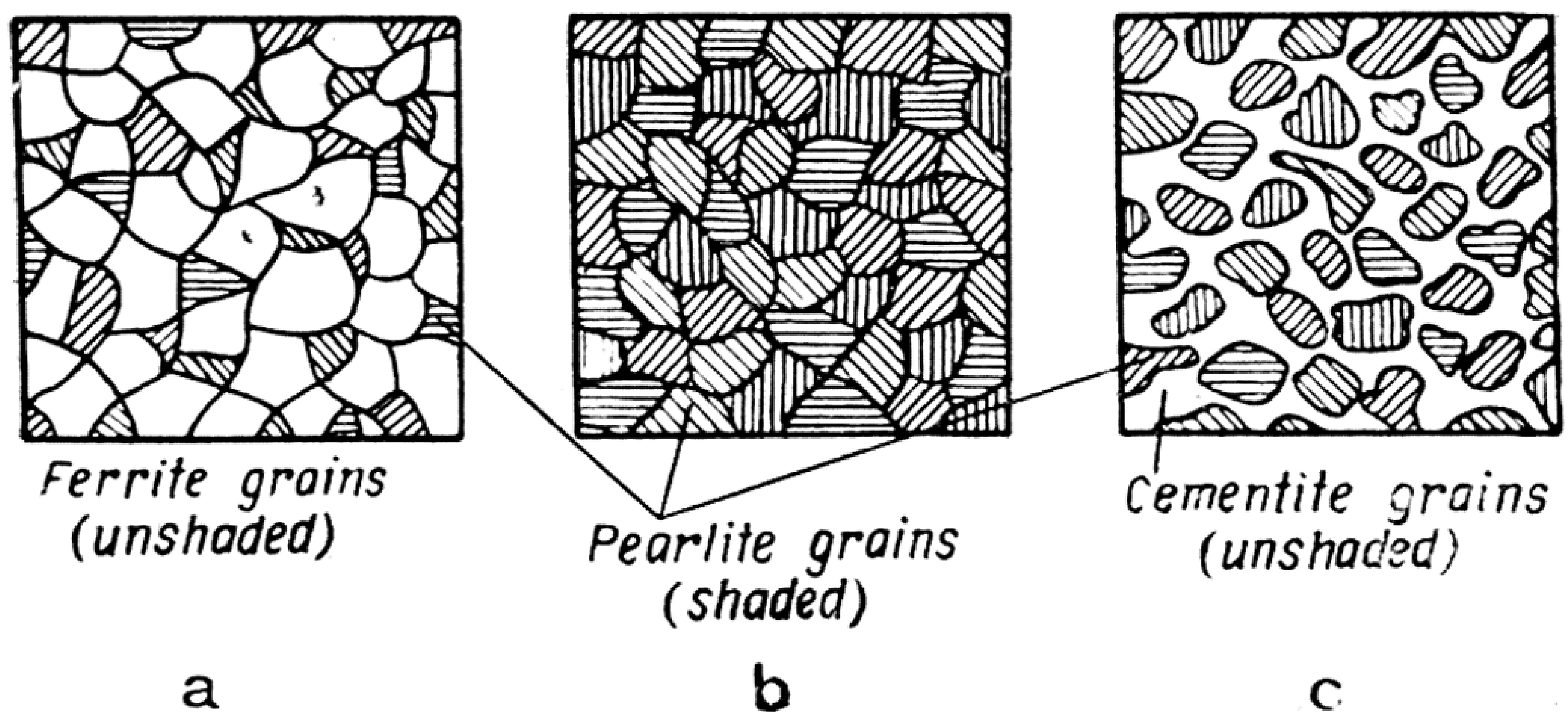


Fig. 18. Microstructure of three different grades of carbon steel:
a) grade Ст.5 steel; b) grade У9 steel; c) grade У12 steel

Any one steel can contain simultaneously the following combinations of grains: 1) grains of ferrite and pearlite; 2) pearlite grains only; 3) grains of pearlite and cementite. The presence of any given combination of grains in a steel depends on its carbon content. The structure of all carbon steels containing less than 0.9 per cent of carbon, i. e., steels of grades Ст. 0, Ст. 1, Ст. 2, Ст. 3, Ст. 4, Ст.5, Ст. 6, Ст. 7; 0.8, 10, 15, 20, 30, 35, 40, 45, 50, 55, 60, 65; У7, У7А, У8, У8А, У8Г and У8ГА, in the annealed condition and at normal temperature, consists of ferrite and of pearlite (see Fig. 18, *a*). Moreover, the greater the carbon content of the steel, the more pearlite and the fewer ferrite grains will it have. Steels of this group are known as hypo-eutectoid steels.

At normal temperatures, and in the annealed condition, grade У9 steel, which has a carbon content of 0.9 per cent, has a structure consisting of pearlite grains only (see Fig. 18, *b*). This steel is called eutectoid steel.

The structure of steels containing more than 0.9 per cent of carbon, i. e., of grades У10, У10А, У10Г, У12, У12А, У13 and У13А, consists of pearlite and cementite grains (see Fig. 18, *c*). In these steels

ferrite grains are absent; such steels are known as hypo-eutectoid steels.

On heating any grade of carbon steel, no structural changes occur below a temperature of 720°C; at a temperature of 720°C, however, the first profound change in the structure of steel occurs: the pearlite grains are transformed into grains of *austenite*. This transformation consists in that the laminated grains of cementite, which formed, as it were, a frame within the pearlite grain are dissolved in the surrounding iron and become uniformly distributed in it. The austenite grains, which have crystallised out of the grains of cementite, are now no longer complicated grains of pure iron surrounding laminated grains of cementite, but homogeneous grains of a solid solution of carbon in iron.

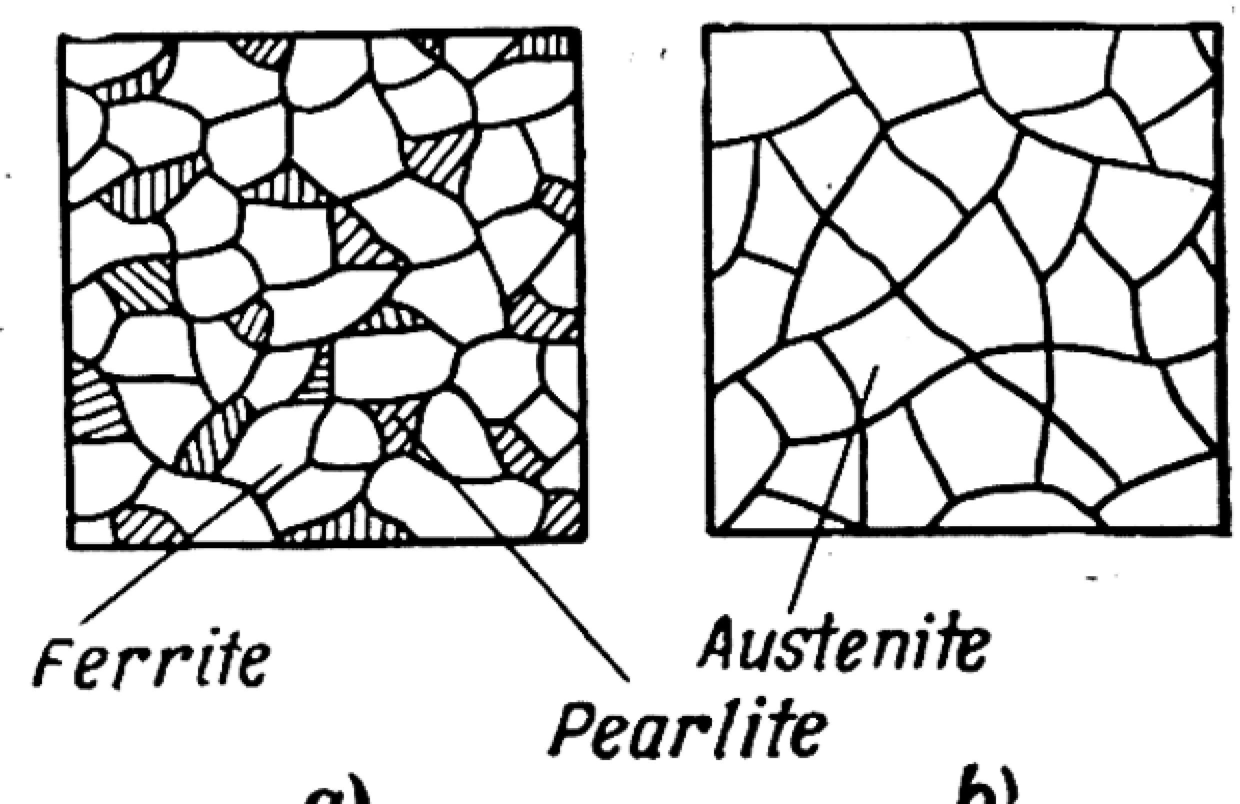


Fig. 19. Microstructure of grade Cт.5 steel

The transformation of pearlite into austenite occurs in carbon steel of all grades when the temperature of the metal reaches 720°C. The temperature, a very important one for the theory and practice of the heat treatment of steel, is called the lower critical temperature of steel, and is denoted by the symbol Ac_1.

What structure will carbon steels have at a temperature slightly above the lower critical point, say at 730°C? It is clear from what has just been said, that at 730° C the structure of steels of the first group, i. e., of steels of grades Cт.0, Cт.1, etc., up to and including grades У8 and У8A, will consist of grains of ferrite and grains of austenite. The structure of steels of the second group, i. e., steels of grades У9 and У9A, at 730°C will consist exclusively of austenite grains. Finally, at 730°C, steels of the third group, i. e., those of grade У10 up to and including grades У13 and У13A, will have a structure of austenite and cementite.

When carbon steels are heated to temperatures over 720°C, the austenite grains grow larger and the ferrite grains smaller because the austenite grains gradually absorb and dissolve the ferrite grains. Finally, at a certain temperature, the ferrite grains will completely disappear, and the metal will have a structure consisting exclusively of austenite (Fig. 19). The temperature, at which the process of the solution of the ferrite by the austenite ends is called the upper critical temperature and is indicated by the symbol Ac_3.

In contrast to the lower critical temperature, which is the same for all carbon steels, the upper critical temperature differs for various

grades of steel. These changes in structure which take place in carbon steels when heated can be represented on a diagram known as the Iron-Carbon Equilibrium Diagram.

In 1868 the Russian scientist D. Chernov first drew attention to the transformations in steel on heating and cooling, and to the relation between these changes and the structure and mechanical properties

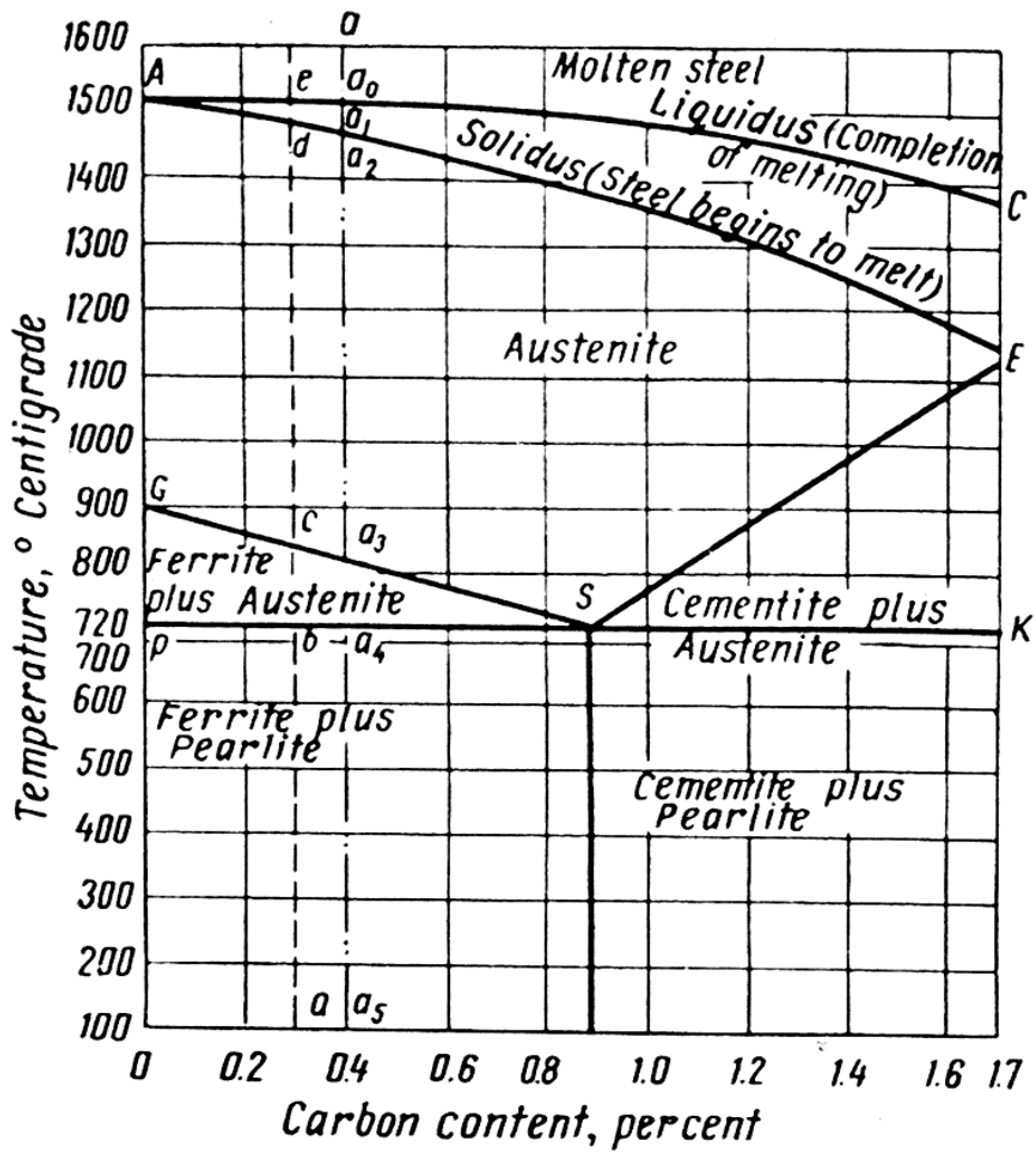


Fig. 20. Iron-Carbon Equilibrium Diagram

of the metal. The Iron-Carbon Equilibrium Diagram was constructed on the basis of his investigations (Fig. 20).

This diagram consists of several lines. Let us consider each one separately. Line *PSK* is the line of the lower critical temperatures of steel, i. e., of those temperatures at which the grains of pearlite begin to transform into austenite. It can be seen on this diagram that *PSK* is horizontal and is drawn at the height of a temperature corresponding to 720°C. This lower critical temperature is the same for all carbon steels.

Lines *GS* and *SE* are the lines of the upper critical temperatures of steel, i. e., of those temperatures above which the structure of any carbon steel will consist exclusively of austenite grains. Various

points on *GS* and *SE* correspond to different temperatures, because the upper critical temperature for each grade of carbon steel will be different.

Line *AE* is the line denoting the temperatures at which steels begin to melt, and *AC* is that of the temperatures at which the melting process is completed. As points on both lines are located at different temperatures, it follows that steels of different grades, i. e., with different carbon contents, melt at different temperatures; moreover, it is clear from this diagram that the greater the carbon content of the steel, the lower its melting temperature.

From this diagram it is easy to follow the changes which occur in the structure of any grade of steel on being heated. Let us take grade Ст.5 as an example. This steel contains 0.3 per cent of carbon. The structural changes in this steel are represented in the diagram by the dotted vertical line (*abcde*). While grade Ст.5 is heated from 20° to 720°C (i. e., to point *b* on the diagram, Fig. 20), its structure consists of pearlite and of ferrite.

At a temperature of 720°C (point *b* on the diagram), the pearlite grains are transformed into grains of austenite. On being heated from 840°C (point *c*) to 1470°C (point *d*), the structure of the steel will consist of austenite only, because at 840°C, i. e., at the upper critical temperature, the last traces of ferrite in the structure of this steel will have disappeared.

At a temperature of 1470°C, the steel commences to melt, and at 1515°C (point *e*) melts completely and becomes a liquid.

RAW MATERIALS USED IN FORGING

Carbon and alloy structural and tool steels are the usual raw materials in forging. In addition, special steels are also used. In forge shops steel is received as ingots or as rolled sections. Ingots are used for manufacturing heavy forgings, mainly for processing in forging presses, while rolled billets are used for lighter forgings.

The quality of the forgings is predetermined by the quality of the raw material. In order to judge the quality of the raw material, blacksmiths must have a good knowledge of the structure of metals, their defects and the causes for the latter.

The Structure of Ingots. After being smelted in the furnace steel is first of all poured into ladles and thence into metal moulds. Here the steel generally solidifies at temperatures of about 1500°C, depending on its grade. After the ingot has solidified completely it is withdrawn from the mould and sent to the rolling mill or the forge shop.

If we cut an ingot longitudinally, plane, polish and etch the surface of its section with suitable reactives, we obtain what is called a

macrosection of the ingot (Fig. 21). On this macrosection it is quite easy to see with the naked eye that the structure of the ingot is by no means uniform along its length and cross-section.

The theory of the structure of ingots was first elaborated in 1878 by D. Chernov, the great Russian metallurgist and scientist.

To obtain an idea of the structure and defects of an ingot, let us follow the process of the solidification of steel in moulds. Let us take a mould into which a steel containing 0.4 per cent of carbon has been poured. According to the Iron-Carbon Equilibrium Diagram (Fig. 20) the temperature of steel just poured into a mould will correspond to point *a*; and the steel will cool in the interval between points a_0 and a. At a_1 the steel will commence to solidify, and will continue to solidify during the temperature interval corresponding to that between points a_1 and a_2. At a_2 the solidification of the steel will be completed, and below this point the steel will continue to cool in a solid state.

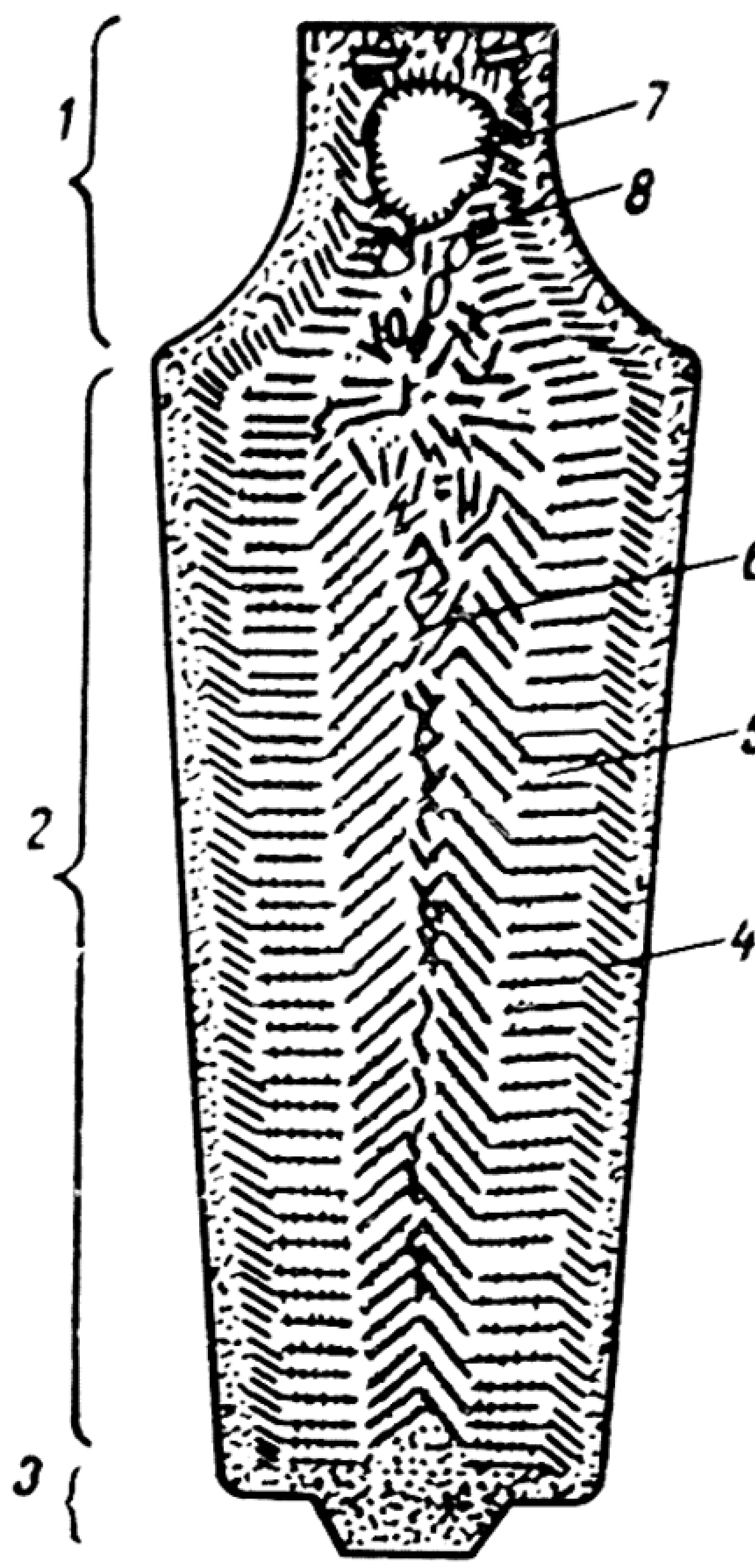


Fig. 21. Longitudinal section of an ingot

As a result of the great difference in temperature between the liquid steel (1500°) and the walls of the mould, a thin, fine-grained crystal skin *4* will form on the surface of the steel ingot immediately after the steel has been poured into the mould (Fig. 21). As the walls of the mould become hotter, the cooling, and, consequently, solidification of the steel will slow down. The steel solidifies in the form of elongated crystals *5*, called *dendrites*, which develop perpendicularly to the walls of the ingot mould. Near the centre of the ingot the crystals lose their definite direction (orientation). The nearer to the centre of the ingot *6*, the larger the crystals become. At the top of the ingot is located the shrinkage cavity *7* as it is called while shrinkage pipe *8* is located immediately beneath the shrinkage cavity.

Shrinkage cavities are due to the rapid cooling of the upper layers of the metal and the consequent formation on its surface of a hard skin. The lower layers remain liquid longer and, as they cool, contract; the upper, solid skin, however, cannot follow the metal as it shrinks and a shrinkage cavity is therefore formed in the head of the ingot.

The shrinkage pipe is, as it were, a continuation of the shrinkage cavity; and in the vicinity of this pipe the metal is very porous.

If a steel ingot is analysed in various places along its cross-section, it will be found that the content of carbon, phosphorus, sulphur and other elements varies in different places: there will be a greater quantity of ingredients concentrated near the centre of the ingot than in its outer layers, and far more in the head of the ingot than in its lower portions. This phenomenon is known as *liquation* or *segregation*, and is explained by the fact that the entire ingot does not cool simultaneously: the purer and consequently more refractory particles of metal will be the first to solidify; the particles of steel containing a greater proportion of impurities and the remains of slag inclusions which solidify at lower temperatures, will be forced towards the central and upper portion of the ingot and, solidifying last, will consequently accumulate under the shrinkage cavity. Therefore in an ingot the metal nearer the surface is always purer than that at its core.

As the steel solidifies, it evolves gases which, if they fail to escape in time, will remain imprisoned in the mass of solidified metal to form what are known as *gas bubbles*. During rolling or forging the gas bubbles in the ingot are frequently eliminated, but not entirely. When ingots are rolled or forged, the remaining bubbles form cracks or *hair seams*, which reduce the strength of the steel and sometimes cause spoilage.

Slag inclusions which are retained in the steel when it solidifies are drawn out as threads during the forging or rolling process in the rolling direction or broken up into smaller particles. Slag inclusions cause minute cracks and hair seams, and frequently lead to spoilage of work.

Blebs are formed on the surface of the ingot when the steel is poured into the mould. The liquid metal splashes up when it hits the bottom of the mould. These splashes, in the form of large and small drops of liquid metal, stick to the walls of the mould, where they solidify and their surfaces become oxidised. As the pouring is continued further, portions of the liquid steel fail to fuse completely with these solid drops, which remain on the surface of the ingot to form what are known as blebs.

Cracks are formed during the process of solidification of the metal and the development of internal stresses within it. Shallow surface cracks are chiselled out. Ingots in which deep cracks are found are scrapped.

An ingot can be divided into three parts: the top, or head discard *1* (see Fig. 21); the central part, or body *2* and the lower, or bottom discard *3*. The head discard and bottom discard are cut off before forging, since the metal contained in the head and tail sections of an ingot is of poor quality. The head generally weighs from 20 to 25 per cent, and the tail 5 to 10 per cent of the total weight of the ingot.

Only the central section of an ingot is used for forging, because only this part is considered to be of good quality: the central portion weigh- about 60-80 per cent of the total weight of the ingot. However, even this central part may also possess surface defects which must be removed before forging. These defects include: blebs, cracks, swellings and interposed foreign matter, such as sand, slag, etc. Unless they are removed, they will be forged into the work during the forging process, thereby lowering its quality and, in some cases, causing the forging to be scrapped.

Shapes and Dimensions of Ingots. Cast ingots may be round, square, rectangular or polyhedral in cross-section. The shape and cross-section of an ingot depend on its designation, dimensions, the grade of steel employed and its further processing, i. e., on whether the ingot is to be rolled or forged.

As a rule large ingots for forge shops are cast with polyhedral and, more frequently, octagonal cross-sections. Smaller ingots, particularly of high and extra high-grade steels, are cast with square or round cross-sections. The dimensions and weight of ingots intended for forging depend on the weight of the forgings to be produced and on the capacity of the forging equipment available. As regards weight, ingots range from several score kilograms to 350 tons.

Appendix 1 gives the approximate weights and dimensions of ingots cast in one of the engineering plants of the Soviet Union.

To ensure high quality, forgings should be made from ingots weighing as little as possible for the following reasons:

1) The degree of liquation, i. e., the amount of slag inclusions and gas bubbles, decreases with the weight of the ingot;

2) The thickness of the more homogeneous and better quality outer metal layer will be comparatively greater in lighter ingots than in heavier ingots;

3) The lighter the ingot, the fewer internal stresses will arise in the steel when it solidifies in the mould.

Roughed, Rolled and Pressed Stock. Roughed, rolled and pressed stock is used in forging operations. Roughed stock (blooms) is obtained by rolling the ingots in roughing, or cogging mills (blooming mills); rolled stock—by rolling the ingots in section rolling mills, while pressed stock is obtained by processing the ingots in horizontal presses. Pressed stock is manufactured from non-ferrous metals only (brass, duraluminium), usually of round cross-section. The cross-sectional structure of heavy roughed and rolled stock is not uniform: it is coarse-grained in the centre and fine-grained nearer the surface. This structure is retained from the original ingot. In the ingots as cast, the crystals are orientated in all directions, while in the blooms and rolled stock they are drawn out in the direction of rolling, i. e., longitudinally.

Nowadays the following profiles are employed for roughed and rolled stock (Fig. 22): 1) blooms cogged in blooming mills; 2) round and square bar stock; 3) rolled flat sections; 4) plates; 5) rolled shapes. Heavy blooms are square in shape (Fig. 22, *a*), with convex sides and rounded edges. The length of side *a* in blooms ranges from 140 to 450 mm. Round stock is manufactured with diameters *d* from 5 to 200 mm (Fig. 22, *b*).

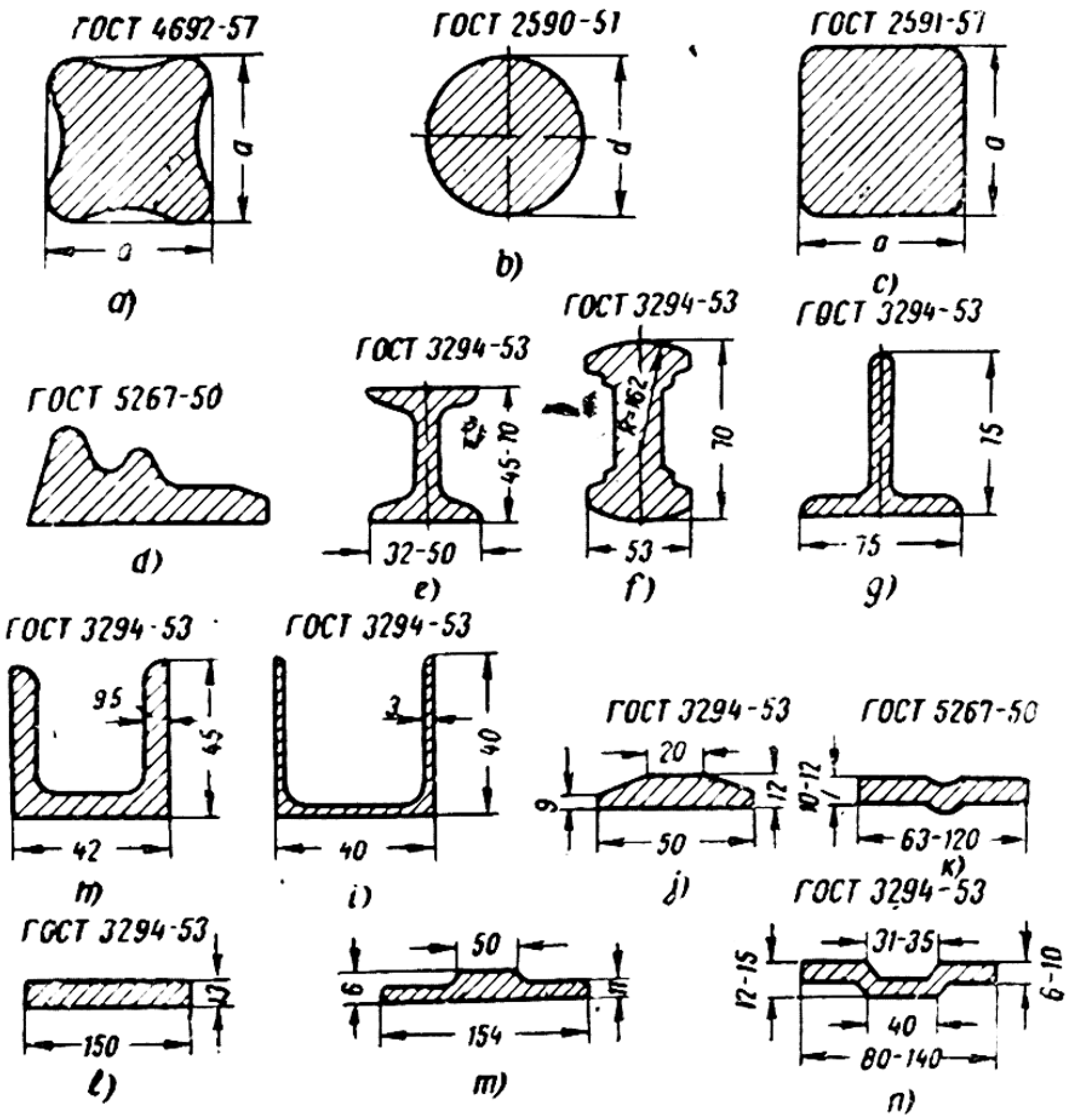


Fig. 22. Rolled sections

Rolled square bars are manufactured with rounded and with square corners. The former are manufactured with sides *a* ranging from 50 to 250 mm (Fig. 22, *c*) and the latter—with sides *a* from 5 to 100 mm. The commercial lengths of round and square bar stock range from 4 to 6 metres. Shaped sections (Fig. 22, *d, e, f, g, h, i, j, k, l, m* and *n*), which are employed mainly for stamping, simplify this process and considerably reduce the cost of production.

As a rule, stock delivered to forge shops in the shape of ingots or rolled stock must be accompanied by a certificate indicating the grade of steel, melt number, chemical analysis, dimensions of bars, the weight of the lot, the GOST number and the results of the tests specified by the standard for the given grade. The manufacturing plant must stamp the end of each bar of steel more than 30 mm

thick with the following marks: grade of steel, melt number, and the plant's inspection department stamp. These brands are usually stamped on the side or the end of the bar. In addition to stamping the bars, the manufacturing plant must paint the ends of heavy bars, or the sides of lighter bars, in the colours specified in Tables 3 and 4.

Table 3

Conventional Painting of Steels

Grade of steel	Colour	Grade of steel	Colour
10	White + Black	15Г	Brown + Blue
15	White + Blue	45Г2	Brown + Pink
20	White + Green	50Г	Brown + Red
25	White + Green	55Г2	Brown + Red
30	White + Yellow	60Г	Brown + Violet
35	White + Yellow	65Г	Brown + Violet
40	White + Pink		
45	White + Pink		
50	White + Red		

Table 4

Conventional Painting of Alloy Steels

Grade of steel	Colour of stripe	Colour of circle
15 X	Green	Blue
20 X	Green	Green
30 X	Green	Yellow
35 X	Green	Yellow
40 X	Green	Pink
45 X	Green	Pink
15 XФ	Violet + Green	Blue
20 XH	Blue + Green	Blue
40 XH	Blue + Green	Pink
12 XH2	Blue + Green	Blue
12 HX3	Blue + Green	Blue
15 XA	Green	White + Blue
38 XA	Green	White + Yellow
30 XMA	Pink + Green	White + Yellow
12 XH2A	Blue + Green	White + Blue
42 XH3A	Blue + Green	White + Blue
18 XH3A	Blue + Yellow + Green	White + Green
20 XH3A	Blue + Green	White + Green

CHAPTER III

FUEL AND ITS COMBUSTION

GENERAL INFORMATION

In engineering, those materials which, on combustion, are capable of generating heat energy which can be utilised for industrial purposes, are called *fuels*. The greater the heat generated by the fuel, the better it is. Obviously, in order to evaluate a fuel, we must know the amount of heat which it generates on combustion; for this it is necessary to know the units in which heat is measured.

A special unit has been accepted for measuring the amount of heat generated by any fuel during combustion. It is called the *calorie*. We distinguish the large calorie and the small calorie.

The *large calorie* (abbreviation: Cal) is that quantity of heat necessary to raise the temperature of one kilogram of water one degree Centigrade.

The *small calorie* (*cal*) is that quantity of heat necessary to raise the temperature of one gram of water by one degree Centigrade. It follows that the large calorie is 1,000 times greater than the small calorie.

In technical calculations the large calorie is employed and therefore, when mentioning calories, we will always have in view the large calorie (Cal).

TYPES OF FUEL AND THEIR CHARACTERISTICS

All existing types of fuel are classified as solid, liquid and gaseous fuels. The thermal action of electricity, and pulverised fuels are also utilised for heating purposes. Certain fuels in turn are subdivided into two groups, one of which includes fuels in their natural condition (as mined), these are known as the natural fuels; the second group includes those obtained after processing natural fuels; they are known as artificial fuels.

Solid Fuels include: a) natural fuels: wood, coal, anthracite, peat; b) artificial fuels: charcoal, coke and pulverised fuel, obtained by crushing coal.

Liquid Fuels include: a) natural fuels—crude oil; b) artificial fuels: petroleum, kerosene, petroleum resituum, tar.

Gaseous Fuels include: a) natural fuels—natural gas; b) artificial fuels: producer-gas, obtained by the gasification of various types of solid fuels (peat, wood, coal, etc.); coke-oven, blast-furnace, lighting and other gases.

All fuels consist of the same elements. The difference between the various types of fuels consists in the fact that they contain these elements in different proportions. The elements which go to make up fuels can be divided into two groups. *The first group* includes elements which either burn themselves, or support combustion. Carbon, hydrogen and oxygen are included in the first group. *The second group*, which consists of elements which neither burn nor support combustion, include nitrogen and water (as a liquid or non-decomposed steam). Sulphur stands in a class by itself. Sulphur is a combustible element which generates heat on burning; its presence, however, is undesirable in fuels, as, when it burns, it forms sulphur dioxide which is absorbed by the metal being heated and is detrimental to its mechanical properties.

It has already been stated that the quantity of heat generated by a fuel during its combustion is measured in calories. Each fuel on combustion generates a different quantity of heat. The quantity of heat (in calories) generated during the complete combustion of 1 kilogram of solid or liquid fuel, or of 1 cubic metre of gaseous fuel is called its *calorific value*. For instance, the calorific value of masout is about 10,000 large calories (Cal), of good-quality coal—7,000 Cal, and so on. The higher the calorific value, the more valuable the fuel, since less is required for the generation of the same quantity of heat. A general unit of measurement has been adopted for the purpose of comparing the heat value of fuels: this unit is a fuel possessing a calorific value of 7,000 large calories, and is called *conventional fuel*.

The following natural fuels are most commonly used for burning in forging furnaces and blacksmith's hearths: lignites, coal and gaseous fuel. Wood and peat, which have a very low calorific value, are in practice not used for heating metals.

Lignites. Lignites are geologically the most recent forms of coal. They contain from 9 to 45 per cent of ash. The calorific value of lignites varies from 2,500 to 5,000 Cal. Freshly mined lignites contain a great proportion of moisture (up to 60 per cent). When exposed to air lignites lose some of their moisture, the content of which falls to 30 per cent. They also rapidly decay and crumble. When stored for considerable periods, they are liable to spontaneous combustion.

Coal. Coal is one of the chief fuels used in forging furnaces. Coal is the product of the gradual conversion of vegetable matter over considerable periods of time, in the course of which the coal deposits thus formed are covered with a thick layer of earth. The decomposi-

tion of vegetable matter and its conversion into coal takes place under considerable pressure and in the complete absence of air.

The process of the formation of coal proceeds exceedingly slowly, over many thousands of years. The type of coal and its calorific value depends on the duration of its formation. The best coals for forging furnaces are those with a high content of volatiles, i. e., long-flame and gas coals. The use of long-flame coal ensures a more uniform heating of the metals in the furnace.

Gaseous Fuels. The only existing natural gas is "burning gas", which is evolved from the soil through natural holes or wells. The calorific value of oil (natural) gas is about 8,000-8,500 large calories and in some cases may be as much as 15,000 per cubic metre.

Nowadays natural gas is being utilised on a large scale in industry and for domestic purposes, particularly in the localities where it is found.

Of the artificial fuels, coke, charcoal, liquid, gaseous and pulverised fuels are of special importance for forging production.

Coke. Coke is obtained by distilling coal in special coke ovens in the absence of air. During this process the volatile matters are expelled from the coal to form a gas possessing a very high calorific value, known as coke-oven gas, which is also a very good fuel.

Coke contains about 87 per cent of carbon, 4 per cent of volatiles, 8 per cent of ash and from 1 to 2 per cent of sulphur. In forging practice, coke is mainly used in blacksmith's hearths.

Charcoal. Charcoal is obtained from wood by burning it in special charcoal burning kilns; it is the best fuel for blacksmith's hearths. Charcoal contains very little ash and is practically free from sulphur. Owing to its high cost, however, it is rarely used in forging practice.

Charcoal contains 84 per cent of carbon, 14 per cent of volatiles and 2 per cent of ash. Its calorific value is from 7,000 to 8,000 large calories.

Liquid Fuels. The only natural liquid fuel of any industrial importance is crude oil. Though crude oil is not used as a fuel for forging furnaces, petroleum residuum, which is as a by-product obtained during oil refining, is widely used as a fuel. The composition of petroleum residuum, which is the residue left after the distillation of kerosene and petrol from crude oil, is not constant, but most frequently contains 84-86 per cent carbon, 12.4 per cent hydrogen, 1.3 per cent combined oxygen+nitrogen+sulphur, 0.3 per cent ash and 1-2 per cent of moisture.

Petroleum residuum has a calorific value of 9,500-10,000 large calories.

Gaseous Fuels. Artificial gas fuels are obtained either by gasifying solid fuels in gas producers or as a by-product of other processes, such as, for instance, coke-oven gas, obtained during the coking of

coal; blast-furnace gas, during the blast-furnace process. Coke which is used as fuel for blast furnaces, is produced in special coke ovens at iron and steel plants; and coke-oven gas, which has a calorific value ranging from 4,000 to 5,000 large calories, is obtained as a by-product.

Solid fuels, in order to be more efficiently and conveniently burnt are converted to gas in special equipment called gas producers. For instance, peat producer-gas is obtained from peat, and coke-oven gas—from coal, etc.

The calorific value of a producer-gas depends on the type of fuel from which it is produced, and on the methods of gasification employed. For instance, the calorific value of peat producer-gas is from 1,500 to 1,600 large calories, while that of coal producer-gas is from 1,200 to 1,400 large calories.

Pulverised Fuel. Coal used as pulverised fuel in heating furnaces is crushed in special mills to a fineness of 0.07 to 0.05 mm. Pulverised coal used as fuel enables heating steel to high temperatures.

THE SELECTION OF FUEL FOR FORGING FURNACES

Fuels for forging furnaces must meet the following main requirements:

1) Ensure a required working temperature ranging from 1200 to 1350°C inside the furnace;

2) Comply with the conditions necessary for the compact design of heating furnaces, high efficiency and the most complete combustion possible;

3) Guarantee high efficiency of the furnace;

4) Facilitate the regulation of the thermal conditions with the aid of automatic regulating instruments;

5) Ensure clean and hygienic furnace operating conditions.

The decisive factor in selecting a fuel for heating furnaces is the cost of the heating and the availability of local fuel reserves.

Not all types of fuel can meet the requirements necessary for use in forging furnaces. Heat obtained from *electricity* (electric energy) is the best fuel for forging shops, but its application is extremely limited because it is up to now the most expensive fuel. Moreover, industrial plants frequently do not dispose of sufficient electric energy for heating steel. For this reason electric energy is still employed to a very limited extent in forging practice, although there are forge shops in the U.S.S.R. where steel is heated exclusively by electricity.

Petroleum residuum, or masout as it is also called, is an excellent fuel for forging furnaces, but since it is a very valuable raw material used in the manufacture of many products, its employment has

been curtailed as far as possible. For instance, on distillation masout yields solar, spindle, machine, cylinder and paraffin oils, autol and other valuable industrial products. Moreover, the transport of liquid fuels over long distances from the site of their deposits increases their cost and overloads transport facilities. For this reason the employment of liquid fuels for forging purposes is advisable only in exceptional cases and in regions near their deposits. In districts located far away from oil and other liquid fuel deposits, furnaces operating on liquid fuel should be reconstructed for operation on gas fuels or for utilising local solid fuels.

Gas fuels meet all the requirements for forging furnace fuels. Producer-gas obtained from coal or peat is recommended for forging furnaces. Natural gas is an excellent fuel for forging furnaces. To ensure the necessary steel heating temperature and the conditions for simplifying furnace design, gas fuels should have a calorific value of at least 1,400-1,500 large calories.

Coal and anthracite are the chief solid fuels used in forging furnaces. The main disadvantages of solid fuels are:

1. It is difficult to ensure a constant and uniform temperature in the working chamber of a furnace when burning solid fuels.

2. A considerable excess of air has to be introduced into the furnace to ensure the complete combustion of solid fuels. This creates an oxidising atmosphere in the furnace, increases the loss of metal as scale, and of heat which escapes from the furnace together with the products of combustion discharged as flue gases.

3. Special fire-boxes are required for burning solid fuels; this complicates the design of the furnace and entails extra labour for maintaining the furnace (stokers, ash removers, etc.).

4. The delivery of solid fuel and the accumulation of considerable quantities of ashes in the shops necessitate an increase in the labour force and makes the shops dirty and untidy.

5. Heat conditions in the furnace cannot be automatically controlled in solid-fuel fired furnaces.

Nevertheless, in spite of all the above disadvantages, considerable amounts of solid fuel are consumed in heating forge furnaces. The chief solid fuels used for blacksmith's hearths are charcoal, coke and coal; only in rare cases is gas or masout used for these purposes.

Fuels for blacksmith's hearths should contain as little sulphur as possible, since the steel when it is heated on contacting the fuel, absorbs some of the sulphur; and as has already been pointed out, sulphur is detrimental to steel. The best fuel for blacksmith's hearths is charcoal. The charcoal for this purpose must be dense, and show a bright fracture on being broken; a piece of good-quality charcoal, on being struck, usually rings as clear as a bell. Charcoal contains no sulphur and practically no ash; for this reason it is widely utilised

for heating high-quality steels and is particularly recommended for welding operations. Its only disadvantage is its high cost.

Sintering coal, or so-called "nuts", are considered the best type of coal for blacksmith's hearths. They range in size from 15 to 25 mm in diameter. Good-quality coal should be black in colour, with a tarry shine; on combustion it sinters, forming a hard outer crust, which facilitates the development of a high temperature in the hearth. The main disadvantage of coal as a fuel for blacksmith's hearths is its great ash and sulphur content. Coke is far better than coal for heating blacksmith's hearths; its disadvantage, however, is its high cost.

THE COMBUSTION PROCESS

Combustion is the rapid chemical combination of oxygen with the combustible elements of fuel (carbon, hydrogen and sulphur) accompanied by the evolution of heat and light. Oxygen is delivered to the fire-box together with the air. Dry air consists of two elements—21 per cent oxygen and 79 per cent nitrogen (by volume). Only the oxygen participates in the process of combustion.

Before any fuel can begin to burn, it must be heated to its ignition temperature, at which combustion takes place independently without any further heating. The ignition temperature depends on the type of fuel used and on the conditions under which the combustion process takes place. The ignition temperature of masout ranges from 500° to 700°C, that of coal—500°C, of anthracite—700°C, and wood—300°C. *Carbon* which is the main element of any fuel, forms either *carbon dioxide* (CO_2) or *carbon monoxide* (CO) when burnt. When sufficient amount of air (and therefore of oxygen) is supplied to the fire-box, the combustion of the carbon will take place completely, according to the following equation:

$$C+O_2=CO_2+97{,}650\ \text{Cal.}$$

An insufficient supply of air will result in the incomplete combustion of the carbon, accompanied by the evolution of a much smaller quantity of heat. As a result of the insufficient combustion of the carbon, carbon monoxide will be formed instead of carbon dioxide, according to the following equation:

$$C+\frac{1}{2}O_2=CO+29{,}430\ \text{Cal.}$$

The second combustible element in fuels is *hydrogen* (H_2). The combustion of hydrogen is also accompanied by the evolution of heat:

$$H_2+\frac{1}{2}O_2=H_2O\ \text{(steam)}+57{,}810\ \text{Cal.}$$

From the above equations of the combustion of carbon as the chief combustible element of any fuel we can see that, during its incomplete combustion, i. e., when combustion takes place in the presence of insufficient air, only one-third of the amount of heat will be generated; in this case carbon monoxide (CO) will be produced instead of carbon dioxide (CO_2). Hence it follows that we must always seek to create conditions which will ensure the complete combustion of the fuel, i. e., ensure a quantity of air sufficient for the carbon to burn to form carbon dioxide (CO_2).

Knowing the chemical composition of any fuel, we can always calculate the amount of air needed for its complete combustion. If we divide the amount of air actually delivered to the fire-box for the combustion of 1 kg or 1 cubic metre of fuel, by the calculated, or theoretical amount of air required for this purpose, we obtain a figure known as the coefficient of surplus air. It follows that the *coefficient of surplus air* is the ratio between the amount of air actually needed for the combustion of one unit of fuel (1 kg or 1 cubic metre) and the calculated (theoretical) amount of air necessary for this purpose.

Example. It is calculated that 10.4 cu. m of air are required for the combustion of 1 kg of masout. Determine the amount of air required in practice for the combustion of one kg of masout, if the coefficient of surplus air is 1.15, i. e., 15 per cent.

Solution. The amount of surplus air needed for the combustion of 1 kg of masout, in addition to the theoretical amount of air, will be $10.4 \times 0.15 = 1.56$ cu. m. The practical amount of air will be: $10.4 + 1.56 = 11.96$ cu. m per kilogram of masout.

The following coefficients of surplus air have been determined for the combustion of various fuels in heating furnaces: for coal—1.3-1.5 (30-50 per cent); for gas fuels burnt in flame burners—1.15-1.2 (15-20 per cent); for gas fuels burnt in non-flame burners—1.1-1.15 (10-15 per cent); for masout—1.2-1.25 (20-25 per cent); and for pulverised fuels—1.2-1.25 (20-25 per cent).

We must always strive to ensure the *complete* combustion of our fuel with a minimum coefficient of surplus air. The surplus air delivered into the furnace is not utilised for burning the fuel; it is heated to the ignition temperature of the fuel and, together with the flue gases, carries away an extra amount of heat, thus increasing the consumption of fuel and the degree of oxidation of the steel in the furnace.

The question arises: how can a worker know whether he is heating the furnace properly, whether he is delivering sufficient air to the furnace, and whether he should increase the air supply?

Usually workers have to judge the completeness of combustion by the colour of the flames. A great excess of air results in a short, sharp

flame consisting of small bright tongues. Steel should never be heated with such a flame, because in this case the heating is never uniform; moreover, when such a flame contacts the surface of the steel, local burning and even fusing of the metal can occur. To avoid this, the amount of air must be reduced until the resulting flame is longer and the entire working chamber of the furnace is filled with a milk-white flame without any bright tongues.

Insufficient air results in a long red flame streaked with black. A considerable insufficiency of air will result in the discharge of dense clouds of black smoke from the furnace. In addition to these external signs indicating the process of the combustion of the fuel, special instruments are employed for analysing the composition of the flue gases; from their composition it is possible to judge whether the combustion is proceeding properly or not.

THE COMBUSTION OF SOLID FUELS

The following types of fire-boxes are employed for burning solid fuels in forging furnaces:

1) Horizontal grate fire-boxes;
2) Inclined step-grate fire-boxes;
3) Mechanical stokers.

Fig. 23 shows a fire-box with a *horizontal grate*. The fuel is delivered to the fire-box through charging door *4* onto a special metal grate *3*. This grate consists of separate cast-iron grate bars (or plates). Ashpit *1*, into which the ash falls, is located under the grate; the air necessary for supporting the combustion of the fuel also enters through the ashpit, being delivered by a fan through pipe *5*. From the ashpit, the air flows through the openings in the grate and the layers of fuel, contacts the latter and combustion takes place, i. e., the combination of the combustible elements of the fuel with the oxygen of the air.

The space *2* in the fire-box above the grate *3* is called the firing space; here the volatile substances of the fire undergo combustion.

Fig. 24 illustrates the *scheme of the combustion* of coal in fire-boxes. Upper layer *4* consists of fuel, freshly delivered to the fire-box, which is prepared for combustion and from which the gaseous products evolve. The most intensive combustion takes place in central layer *3* while the final combustion of what is known as "tails", and the heating of the air supplied for combustion takes place in lower layer *2*, which consists of tails and ashes. The layer of ashes also protects the grate bars *1* against the action of high temperatures.

A thin layer of fuel (in the absence of a lower layer of ashes) will result in an uneven distribution of the air through the grates, i. e., air will not penetrate the layers of fuel equally everywhere. This

circumstance, when burning sintering coal or coal in large lumps, will result in uneven burning, and however much the operator may stoke and level the layers of fuel, he will never be able to fire the furnace properly. With small lumps of non-sintering coals this does not occur. The air will be distributed more uniformly through the grate, but, on the other hand, due to the small size, and consequently light weight of some of the coal particles, it will carry away part of the coal dust from the fire-box, thereby increasing the consumption of fuel.

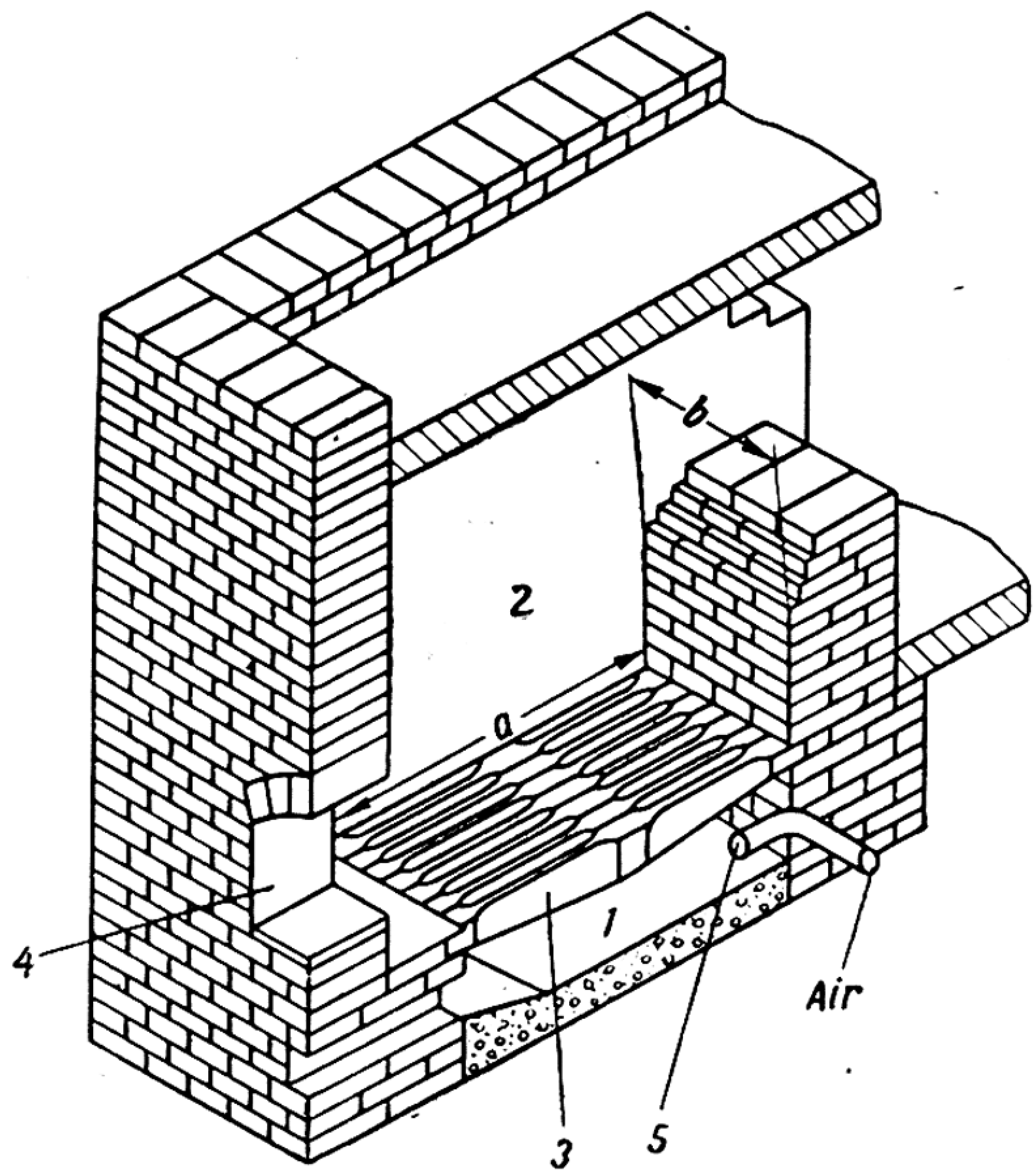


Fig. 23. A horizontal grate fire-box

The combustion process is altogether different over an ash (slag) bedding, when fresh fuel is laid over a layer of coke and slag. In this case, the air penetrating through the considerable number of crooked channels formed by the slag and tails, will be uniformly distributed over the grate and also uniformly heated. And since in this case the pressure of the air will be considerably reduced no coal dust will be carried away and the combustion process will thus be quieter and more uniform.

It follows from this that, when burning coal on horizontal grates, we must:

a) Burn the coal on a bed of slag;

b) Maintain the thickness of the fuel layer from 80 to 200 mm, depending on the size of the coal. The greater the size of the lumps, the greater must be the thickness of the coal layer on the grate; best results are obtained with lumps of coal from 30 to 50 mm in size;

c) Stoke the fire-box to loosen and level the top layers of coal. It is completely incorrect to clear out *all* the ash into the ashpit stoking the fire-box. If, however, the grate is choked up with ashes, it should be carefully cleared with a poker, so as to permit the entrance of air;

d) Charge fresh fuel in small portions at the shortest possible intervals (every 5-8 minutes). Coal should be thrown into the fire-box so that each addition of coal completely covers the thinner parts of the previous layer. These thin parts can be recognised by the bright colour of their surface.

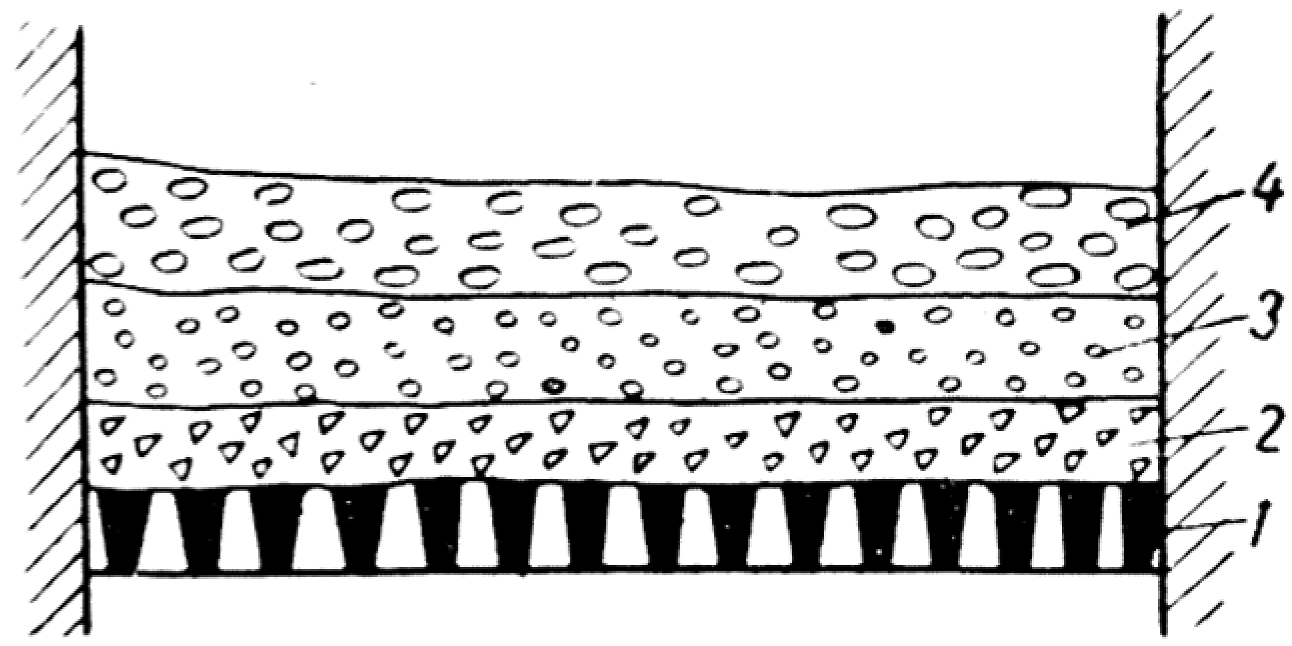


Fig. 24. Scheme of combustion of coal on a grate

The quantity of fuel burnt in the fire-box depends chiefly on the area of the grate and its load. The area F of the grate (Fig. 23) can be found from the formula:

$$F = a\,\delta \text{ m}^2$$

where a—the length of the grate in metres,
and δ—the width of the grate in metres.

The area is calculated from the load rate on the grate. By the *load rate on the grate* we understand that weight of fuel B which is consumed in one hour per square metre of the grate area (kg/m²/hr). As it can be recommended to burn 100 kg of conventional fuel per hour per sq. metre of grate area, then:

$$F = \frac{B_{conv}}{100} = \frac{B \cdot Q}{Q_{conv} \times 100} \text{ sq.m}$$

where Q is the calorific value of the fuel in large calories. The calorific value of conventional fuel, as stated in Section 18, is 7,000 Cal.

Example. Determine the area of a grate, if the consumption of coal is 200 kg per hour; the calorific value of the coal being 5,600 Cal.

Solution. Substituting the given values in the formula, we obtain:

$$F = \frac{200 \times 5{,}600}{7{,}000 \times 100} = \frac{1.120{,}000}{700{,}000} = 1.6 \text{ sq.m.}$$

Grates consist of separate fire-bars of the *beam* or of the *plate type* (Figs. 25 and 26). Usually fire-bars of the following dimensions are employed: length from 500 to 1,000 mm; width *a* of beam-type fire-bars—from 50 to 70 mm, and of plate-type fire-bars—from 150-250 mm. Beam-type fire-bars are employed for burning coal; plate

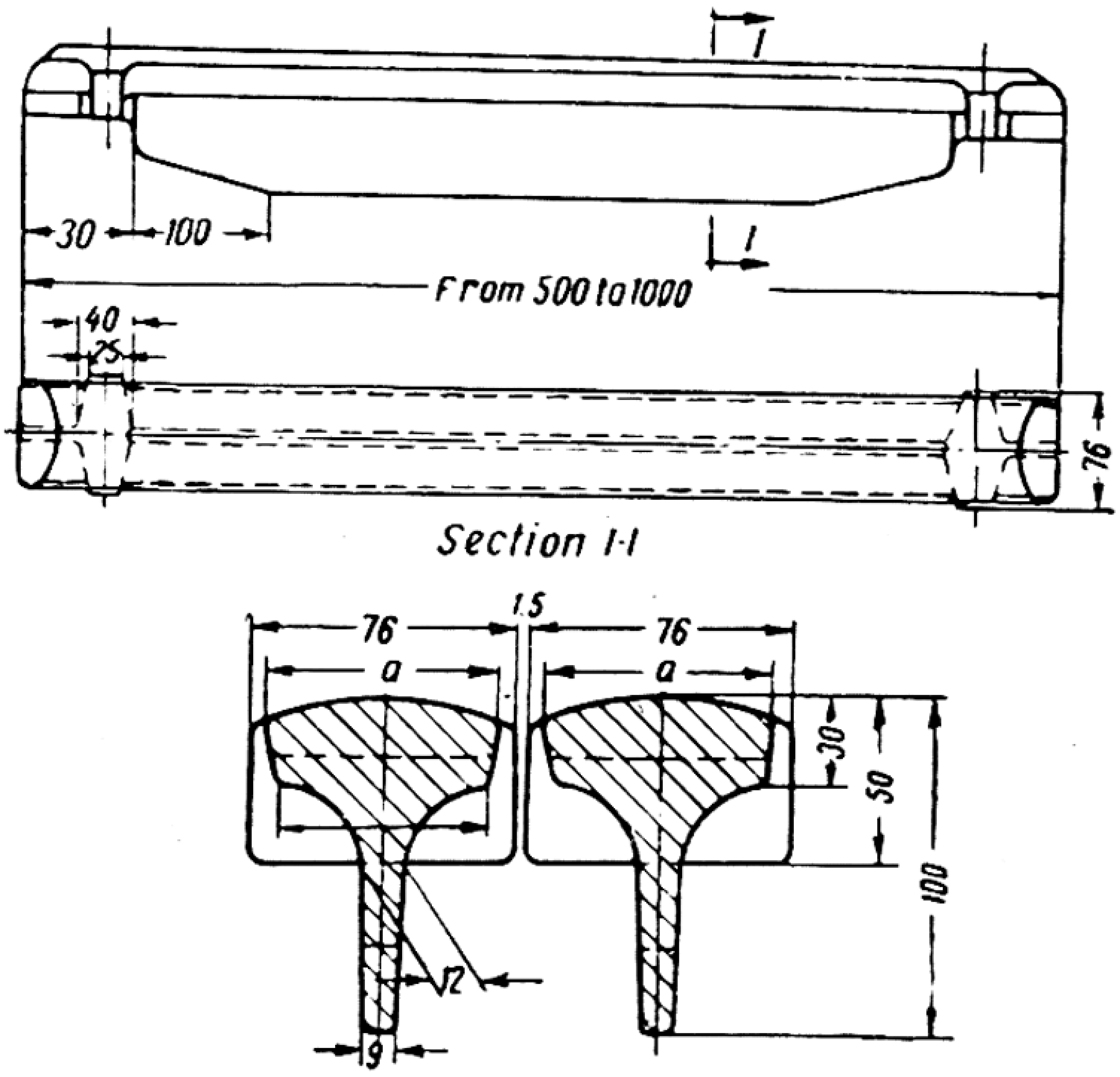


Fig. 25. Beam-type fire-bars

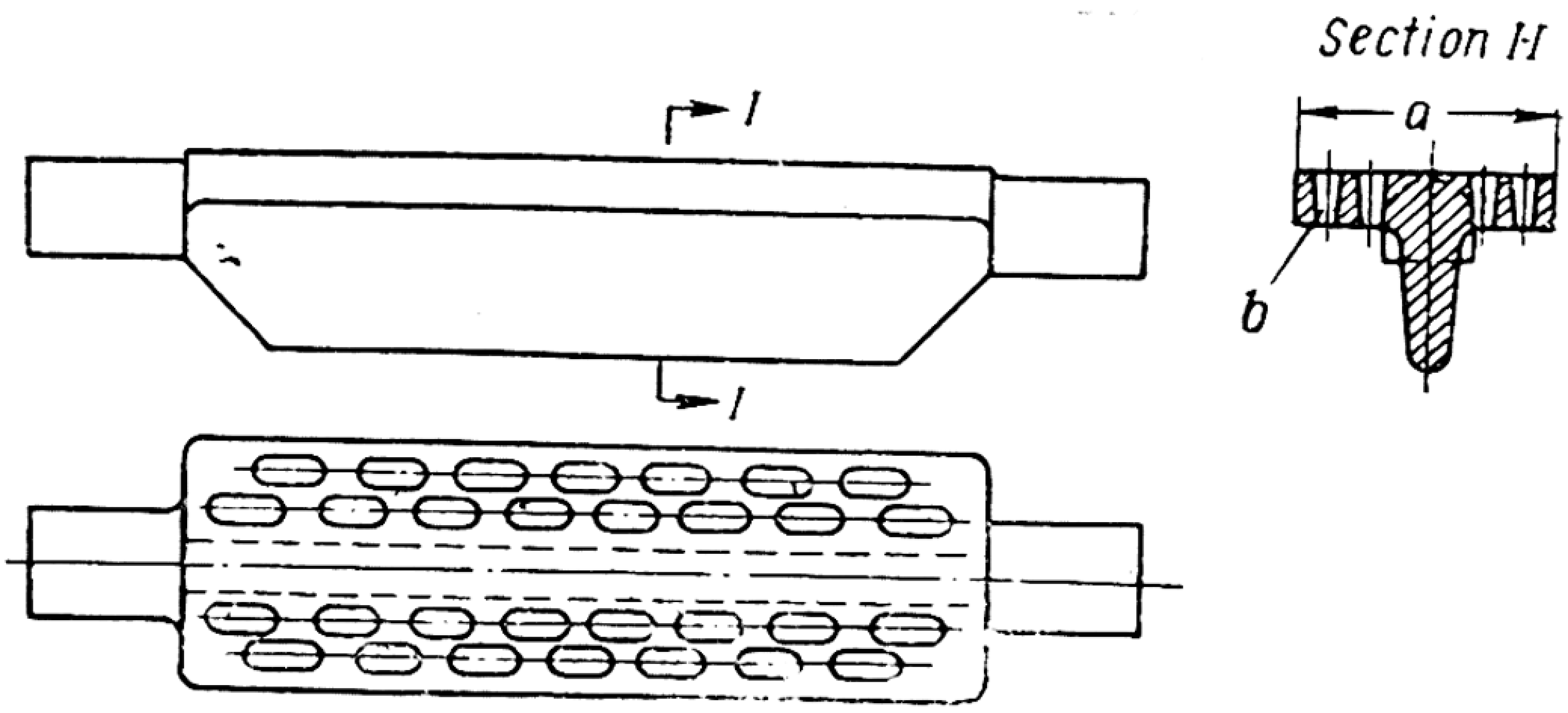


Fig. 26. Plate-type fire-bars

(flat) type fire-bars are employed for burning fine coals and anthracite.

The spaces *b* through which the air from the ashpit penetrates into the fire-box is called the *live section* of the grate; the dimensions of this live section depend on the ratio of its area (in per cent) to that of the grate. The live area of a grate with beam-type fire-bars is formed

by bosses, which form spaces between the fire-bars (in Fig. 25, the spaces b equal 1.5 mm).

The live section of plate fire-bars is formed by slots 5-8 mm wide (see Fig. 26). The size of the live section is determined by the type of fuel employed and varies from 10 to 20 per cent of the grate area. The length and width of the grate depend on the working conditions, and do not exceed 2,000 mm and 1,200 mm respectively per charging door.

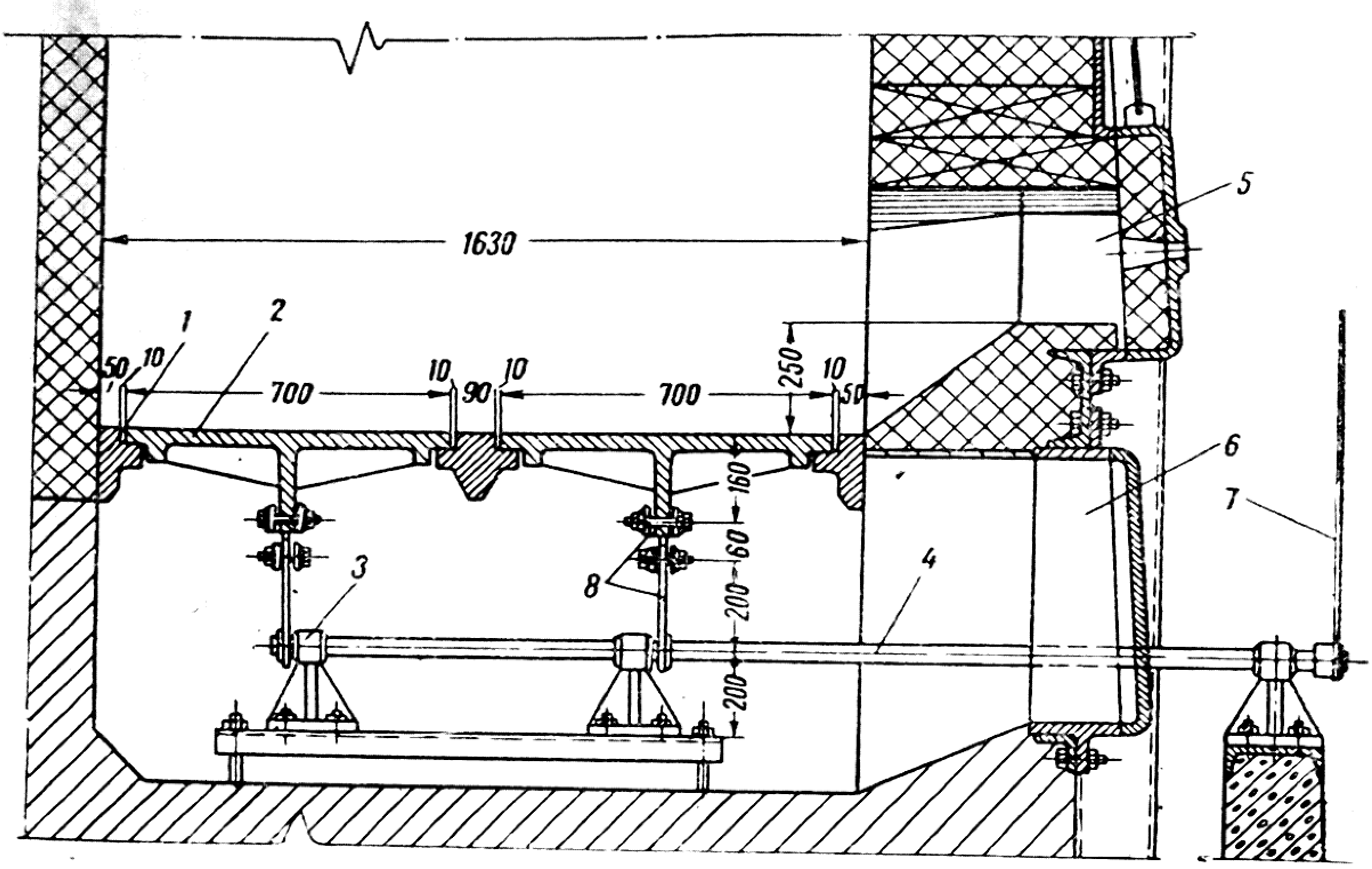


Fig. 27. Fire-box with shaking fire-bars:
1) grate bar supports; 2) shaking plate-type fire-bars; 3) bearings; 4) shaft; 5) charging door; 6) ash-removing door; 7) tie-rod; 8) levers

In order to facilitate removal of the ashes and to stoke the lower layers of fuel, *shaking* grates are sometimes employed. In such cases, the fire-box is cleared through the shaking grate and the lower layer of fuel is raked with a poker when the fire-bars are periodically swivelled on their trunnions with the aid of tie-rods and a lever (Fig. 27).

Burning coal in fire-boxes equipped with horizontal grates has several disadvantages, the main are:

1) The difficulty of ensuring uniform combustion, especially when burning coals rich in volatiles. These volatiles are discharged in considerable quantities after each stoking operation; this leads to

a reduction of the temperature inside the furnace and a loss of heat which escapes together with the flue gases;

2) The difficulty of maintaining the fire-boxes and of ensuring high temperatures when burning coals with a considerable dust, ash and moisture content.

Fig. 28 illustrates a fire-box equipped with a mechanical fuel feeding device called a *mechanical stoker*. To ensure normal combustion, mechanical stokers should only be used for burning coal with

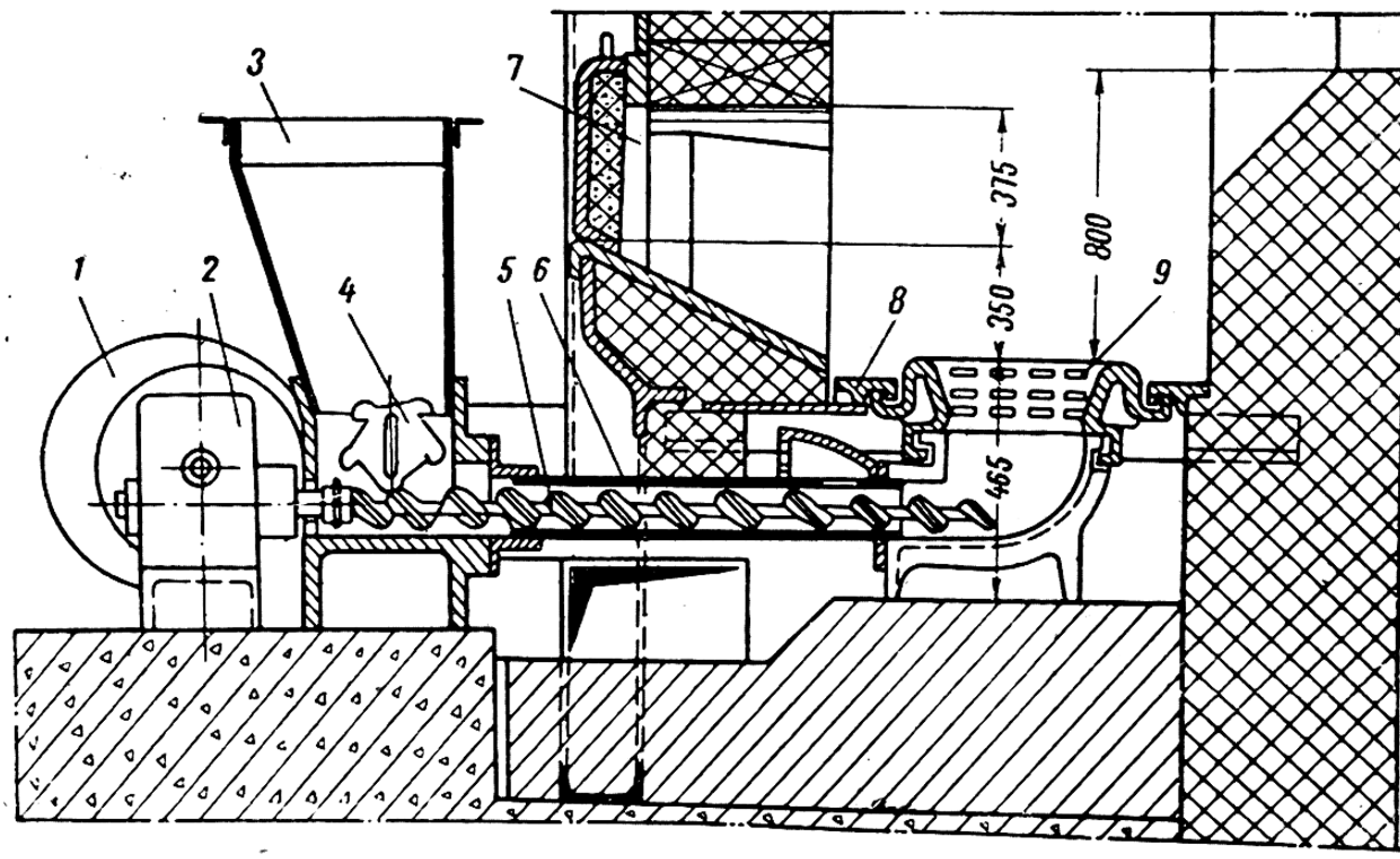


Fig. 28. Mechanical stoker:
1) fan; 2) reductor; 3) coal hopper; 4) coal mixer; 5) worm conveyor; 6) tube; 7) ash-removing door; 8) side plates; 9) retort

a high fusion temperature ash content (i. e., with an ash fusing at temperatures not lower than 1200-1250°C). The lumps of coal should be not less than 30-40 mm in size, and for this reason the coal should be crushed and sorted before burning in mechanical stokers.

The coal is loaded into hopper *3*, whence it is delivered by worm conveyor *5* along pipe *6* to retort *9* (see Fig. 28). Air is delivered into the retort through a slot from fan *1*, which is driven by the motor which also rotates worm conveyor *5*. The coal combustion process takes place in retort *9*. The process of the combustion of coal in mechanical stokers differs from that in horizontal grates. Fresh portions of coal are delivered by the worm conveyor, gradually raised into the retort and gradually heated by the top layers of burning coal. The volatiles evolved by the coal burn completely without forming any smoke or soot. The zone of combustion is located over the surface of the retort.

Slag and ashes are also burnt on the surface of the retort and, owing to the continuous supply of fresh coal from the bottom of the retort, are gradually pushed onto the side plates *8*. The slag and ashes are raked off from these side plates through ash removing doors *7*. The air in mechanical stokers must be delivered under considerable pressure, ranging from 200 to 250 mm water column. The capacity of mechanical stokers is approximately from 100 to 125 kg of conventional fuel per hour.

Mechanical stokers have the following advantages compared with hand-stoked fire-boxes: they ease the work of the operators, reduce the labour force required (one operator can serve 6-8 stokers) and ensure a more uniform temperature in the fire-box.

THE COMBUSTION OF LIQUID FUELS

Masout has the following main advantages compared with solid fuels:

1) High calorific value;

2) Absence of ash, which eliminates the loss of time entailed in cleaning the fire-box and increases the efficiency of the furnace;

3) Convenience in handling and storage. This obviates the accumulation of fuel in the shops, which is inevitable when using solid fuels;

4) Its use facilitates the simplification of furnace design, thereby obviating the necessity of building special fire-boxes; it also facilitates the maintenance of the furnace.

Moreover, automatic devices for regulating the thermal conditions of furnaces can be employed on masout-fired furnaces, and the use of masout leads to more sanitary conditions of furnace operation. Liquid fuels are burnt with the aid of *atomisers*.

Theory and practice have proved that the better the particles of masout and air are mixed, the better and more rapid is its combustion; moreover less air is consumed. Atomisers should therefore atomise the masout as completely as possible in order to ensure its better mixing with the air, thereby ensuring conditions for the more efficient and possibly complete combustion of the fuel. Compressed air or steam is employed for atomising the masout. There are many atomisers of a great variety of design, but, as regards the principle of their operation, they can be divided into two groups: low-pressure and high-pressure atomisers.

Let us first of all understand what is meant by *pressure*, and how it is measured.

The pressure of a blast (of air or of steam) is measured in millimetres of a water column, or in atmospheres. By the pressure of one *atmosphere* is understood the pressure of one kilogram over an area

of one square centimetre. By the pressure of 1 mm of water column is understood the pressure exerted by a load of 1 kilogram uniformly distributed over an area of 1 square metre. One atmosphere is the pressure exerted by 10,000 mm of a water column, or by 760 mm of a column of mercury.

High-pressure atomisers include those which atomise masout with the aid of air or steam under a pressure of two or more atmospheres; *low-pressure atomisers* include those which atomise masout under pressures ranging from 400 to 600 mm of a water column. Fans are employed for delivering air to low-pressure atomisers; high-pressure

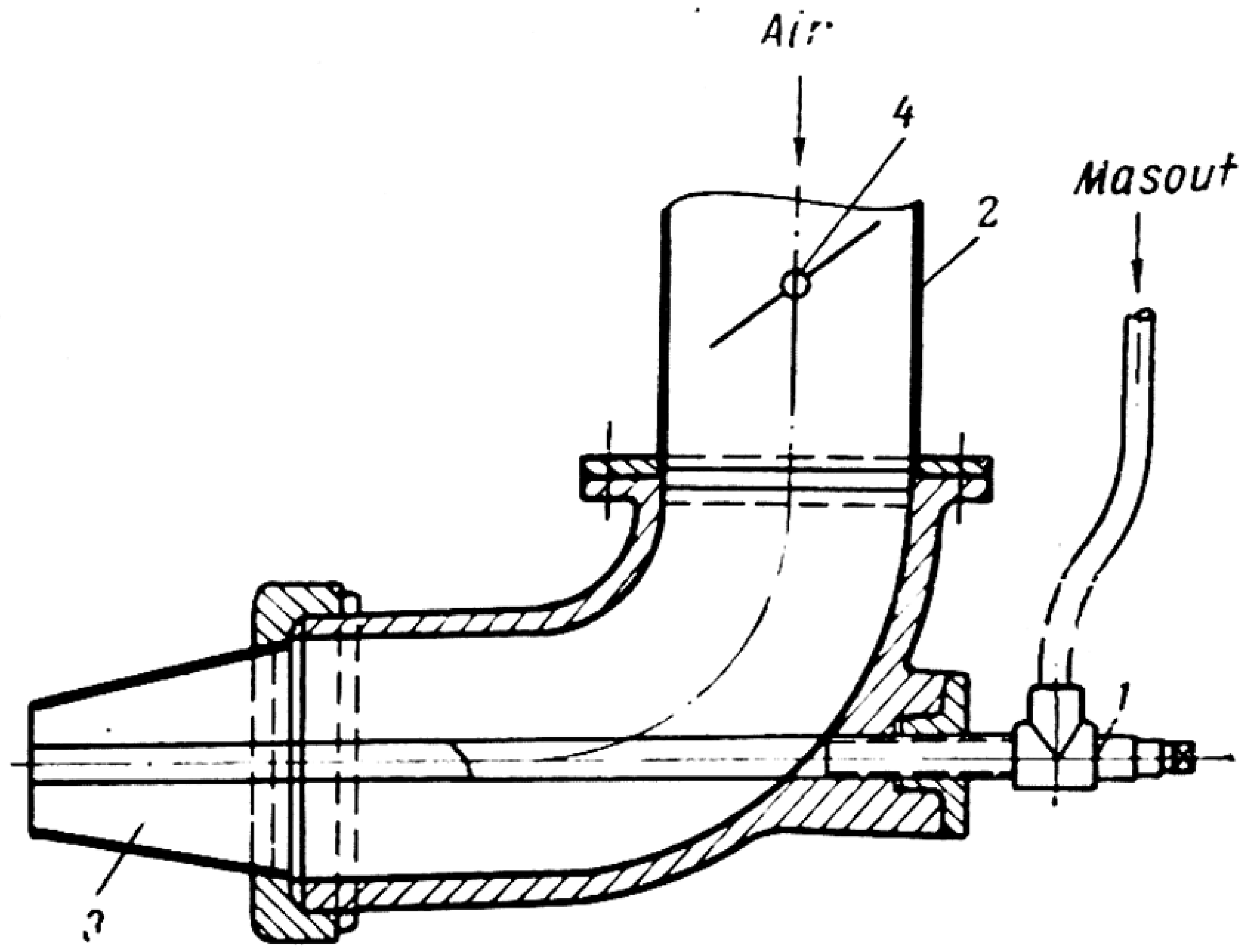


Fig. 29. Low-pressure atomiser

atomisers are supplied with air from compressors. Atomisers are further classified as air and steam depending on the method of atomising the masout.

The more complete the atomisation of the masout is, the less surplus air will be required for its combustion. If masout is properly atomised, the surplus air will vary within a range up to 15 per cent; if the masout is not properly atomised, the surplus air required may amount to 20 or 25 per cent.

In order not to choke the atomiser, the masout should be previously cleaned of all dirt, etc. Special filters are employed for cleaning masout, which is atomised far better if it is preheated to 90-100°C. It is preheated by steam coils located in the tank from which the fuel is pumped to the atomisers. To prevent it from cooling on its way from the pump to the furnaces, the masout is heated by a steam pipe running close to the masout line.

Before considering the design of atomisers, let us consider the requirements which they must meet:

1) The atomiser should be able to effect a proper atomisation of the masout;

2) The atomised masout must be thoroughly mixed with the air necessary for combustion;

3) The atomiser must be of a simple and reliable design;

4) All parts of the atomiser liable to come in contact with high temperatures must be interchangeable.

The atomiser shown in Fig. 29, is designed for *low air pressures*, ranging from 400 to 500 mm water column. It operates as follows: masout is fed into inner pipe *1*, and air—into outer pipe *2*. On leaving nozzle *3* the stream of air draws along the masout and atomises

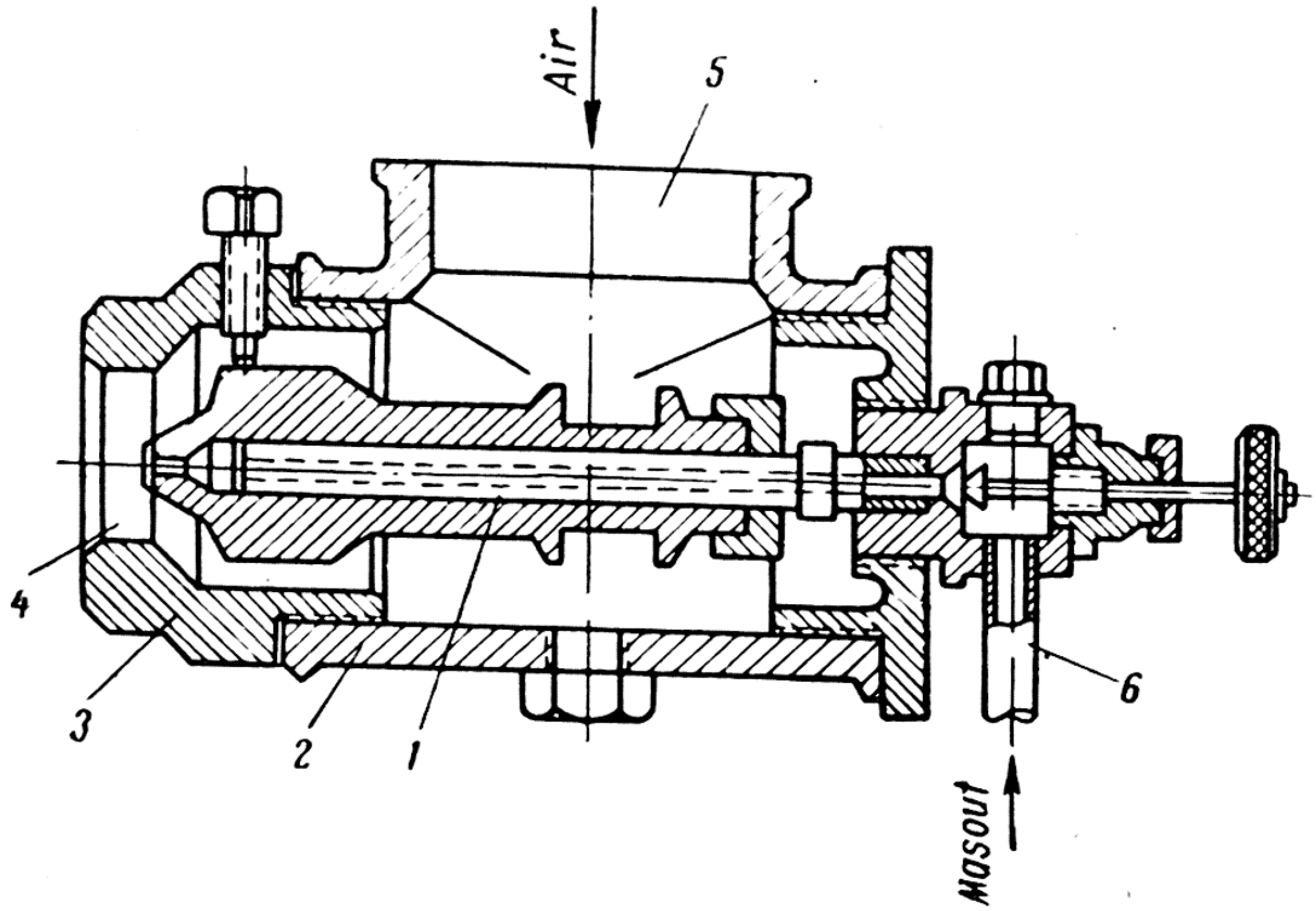


Fig. 30. Low-pressure atomiser

it. The air supply is regulated by valve *4*, and that of the masout by a valve installed on the masout line.

This atomiser has one great disadvantage: if the flow of the masout is reduced, the speed of the air is liable to fall, which is detrimental to atomisation. In fact the volume of air delivered to the atomiser will fall with a reduction of the flow of the masout; but the size of its outlet from the atomiser remains constant; the air will therefore leave the atomiser at a slower speed and the atomisation will be impaired.

There are, however, atomisers of other designs which do not possess this disadvantage. One of these atomisers is illustrated in Fig. 30.

Here the speed of the atomisation of the masout can be kept constant under all conditions of combustion. It operates as follows: masout is fed along pipe *6* into masout line *1*, equipped with a conical tip. Air flows along pipe *5* and is directed through air nozzle *3* onto the outgoing stream of masout at a large angle to its flow,

atomising and ejecting it into the fire chamber. A constant rate of atomisation is ensured by shifting the masout pipe with its conical tip along housing *2* of the atomiser. By shifting this tube towards the outlet *4* (to the left), the cross-section of the latter is reduced, while it will be increased on shifting the tube in the opposite direction. Consequently, depending on the volume of air being fed to the atomiser, we can change the cross-section of the air nozzle and thereby maintain a constant rate of atomisation.

In spite of its efficient operation, the atomiser shown in Fig. 30 has one disadvantage: when adjusting the atomiser, the masout tube

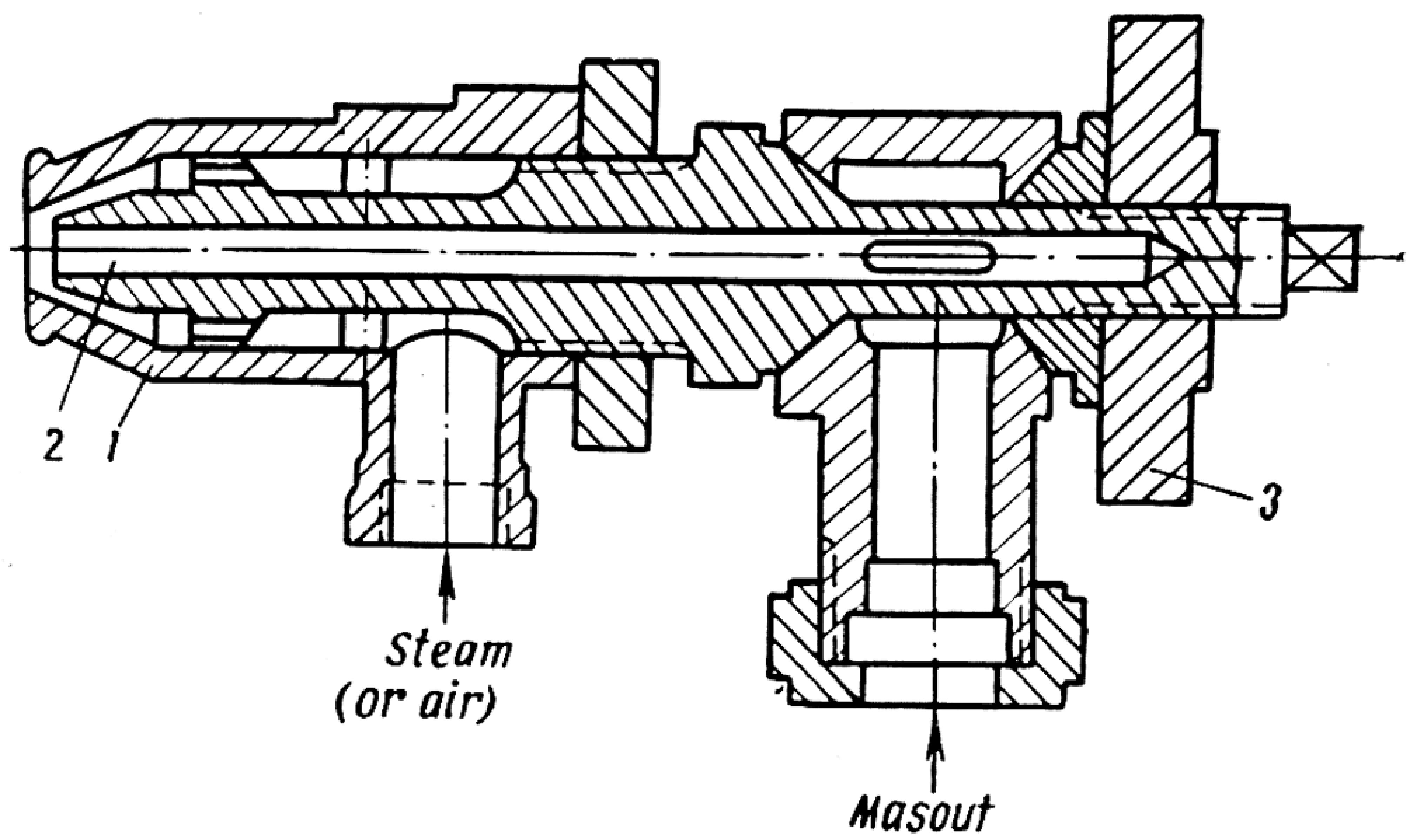


Fig. 31. Shukhov high-pressure atomiser

does not change its position in relation to the end of the air nozzle; this, to a certain extent, impairs the atomisation of the masout and facilitates its leakage.

Low-pressure atomisers are widely employed in forge furnaces, particularly for small furnaces. They give a comparatively short flame, are fairly simple to operate and require no expensive compressor units for delivering air, which can be supplied by ordinary high-pressure (700-800 mm water column) fans.

Of the *high-pressure* atomisers installed on forge furnaces the Shukhov high-pressure atomiser (Fig. 31) is that most widely employed in the Soviet Union. This atomiser comprises two tubes *1* and *2*. Air (or steam) is delivered through outer tube *1*, while masout flows along inner tube *2*. The air (or steam) flows at a considerable speed through the narrow end (the nozzle) of the atomiser forcibly drawing along the masout flowing from the inner tube, and dispersing it in a mist, thereby ensuring better combustion. The operation of the Shukhov atomiser is regulated by: a) adjusting the masout supply with the aid of the valve on the masout line; b) changing the

volume and pressure of the steam or air; and c) by adjusting the position of the masout tube with the aid of handwheel *3*.

High-pressure atomisers give long sharp flames, up to 4 metres in length; they are installed generally in long, high-productivity forge furnaces.

THE COMBUSTION OF GASEOUS FUELS

Gaseous fuels are the most convenient fuels for forge furnaces and possess many advantages. Their main advantages as compared with solid and liquid fuels are the following:

1) Gases can be easily mixed with air and therefore require a small amount of excess air for their complete combustion. This ensures a high temperature of combustion and reduces the losses of physical heat carried away by the flue gases in the form of smoke;

2) The temperature inside the furnace can be easily controlled when firing with gases;

3) The combustion takes place very rapidly with gases, and for this reason special fire-boxes are not required in gas-fired furnaces. The gas burns directly inside the working chamber of the furnace, thereby ensuring a high heat transfer to the metal by the burning gases;

4) Gas-fired furnaces are distinguished by their simple design and low cost, as they require no special fire-boxes for the ignition and combustion of the gas;

5) Gas can be easily delivered from the gas-producing plants to the consuming plants; the gas is supplied to the furnaces through gas lines, specially laid for this purpose;

6) A high temperature can be ensured when firing furnaces with gas, since both the gas and the air can be preheated simultaneously;

7) Gas-firing equipment can be easily installed and ensures automatic regulation of the heat conditions in the furnace;

8) The use of gas leads to better sanitary conditions for the operation of furnaces.

The disadvantage of gas fuels and, in particular, of producer-gas, i. e., of gases specially prepared from solid fuels, is their high expense. But this disadvantage disappears when employing natural gases. The ease with which this gas is produced and its high calorific value make it the cheapest and best gas fuel.

There are several *methods of burning gases*. The chief methods adopted for firing forge furnaces are:

1) Delivering the gas and air simultaneously to low-pressure burners;

2) Delivering the gas to the burners under high pressure with simultaneous suction of air from the atmosphere;

3) Delivering previously mixed gas and air to the burners under high pressure.

Each of these methods possesses its advantages and disadvantages. Nowadays the first method, which is the simplest, is most widely employed; moreover, this method requires burners of simpler design and the air is delivered by fans.

Many different designs of burners are available; we will consider only those which are most widely used for forge furnaces.

Gas burners, like liquid fuel atomisers, are classified as high- and low-pressure burners. High-pressure burners are employed for firing

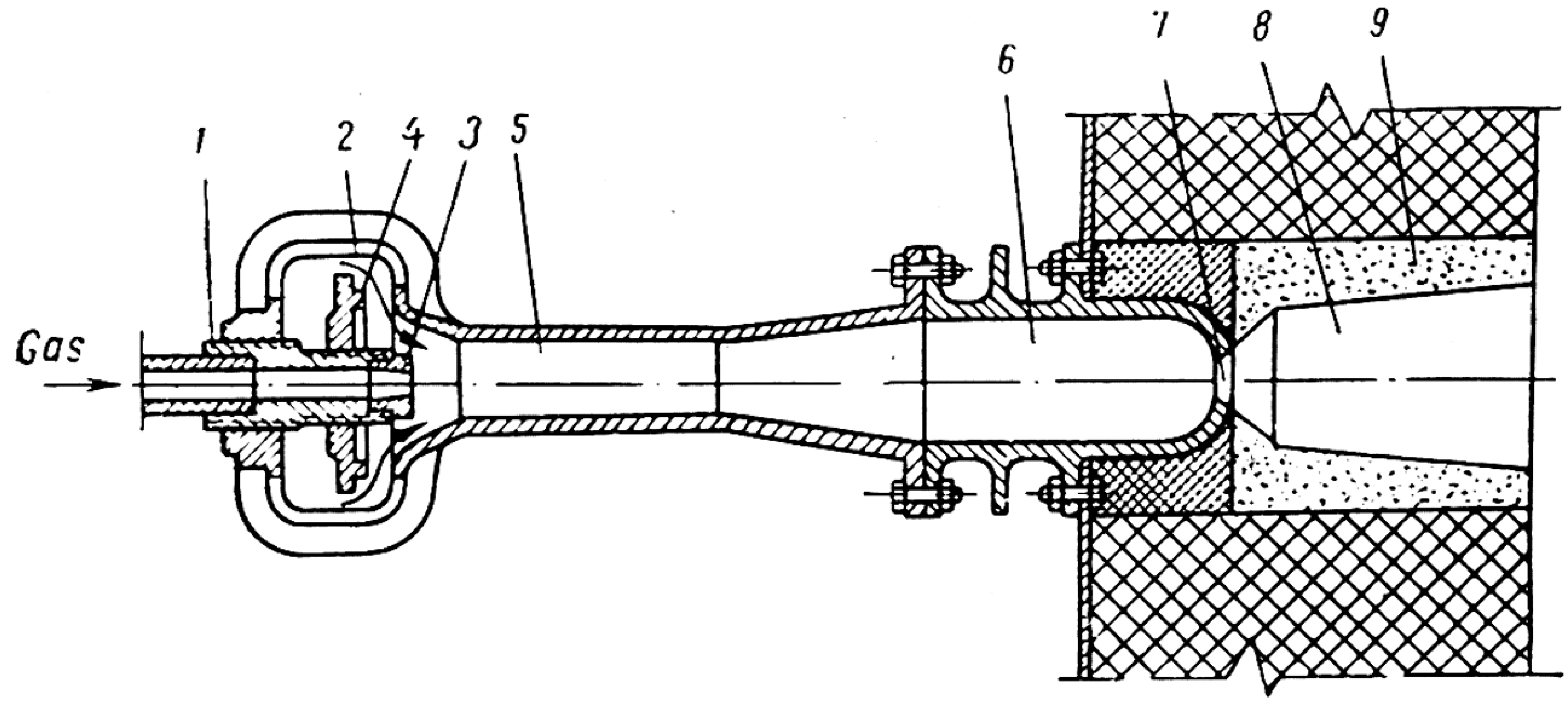


Fig. 32. Injection burner

gas at pressures ranging from 700 to 2,500 mm water column, and even higher. Special gas-blowing installations are built for compressing the gas to such pressures.

Fig. 32 illustrates an *injector-type burner* with an individual mixer; it operates on gas delivered under a pressure ranging from 1,500 to 1,600 mm water column. This burner operates by the second method of burning gas, i. e., the gas is fed to the burner under high pressure, and the air is drawn in from the atmosphere. These burners are also called surface or flameless injection burners. The gas enters the burner through nozzle *3*, injects (draws) the necessary amount of air through slot *2* between air washer *4* and mixer *5*. Air washer *4* is mounted on connecting tube *1*. The amount of air required for combustion is controlled by shifting the air washer along the connecting tube. By shifting it nearer to, or farther from the gas inlet, we can increase or decrease the size of the slot for the suction of air and thereby increase or reduce the volume of air consumed.

Mixer *5* comprises a tube in which the gas and air are mixed. This mixture is delivered to burner *6*, whose end is formed by nozzle *7*.

The combustible mixture is discharged from the burner nozzle into tunnel *8*, where the combustion of the gas takes place. The tunnel is lined with shaped brick or formed out of a refractory mortar *9* in the furnace wall.

Since a previously prepared mixture of gas and air is delivered to the burner, combustion takes place very rapidly, without any visible flame. For this reason injection burners are called flameless burners.

In low-pressure burners (flame burners) the mixing of the gas and air commences in the burners; it is completed in the working chamber of the furnace. The air and gas are delivered to these burners under low pressure. The pressure of the gas before the burner should range from 100 to 300 mm water column, and that of the air—from 150 to 400 mm water column.

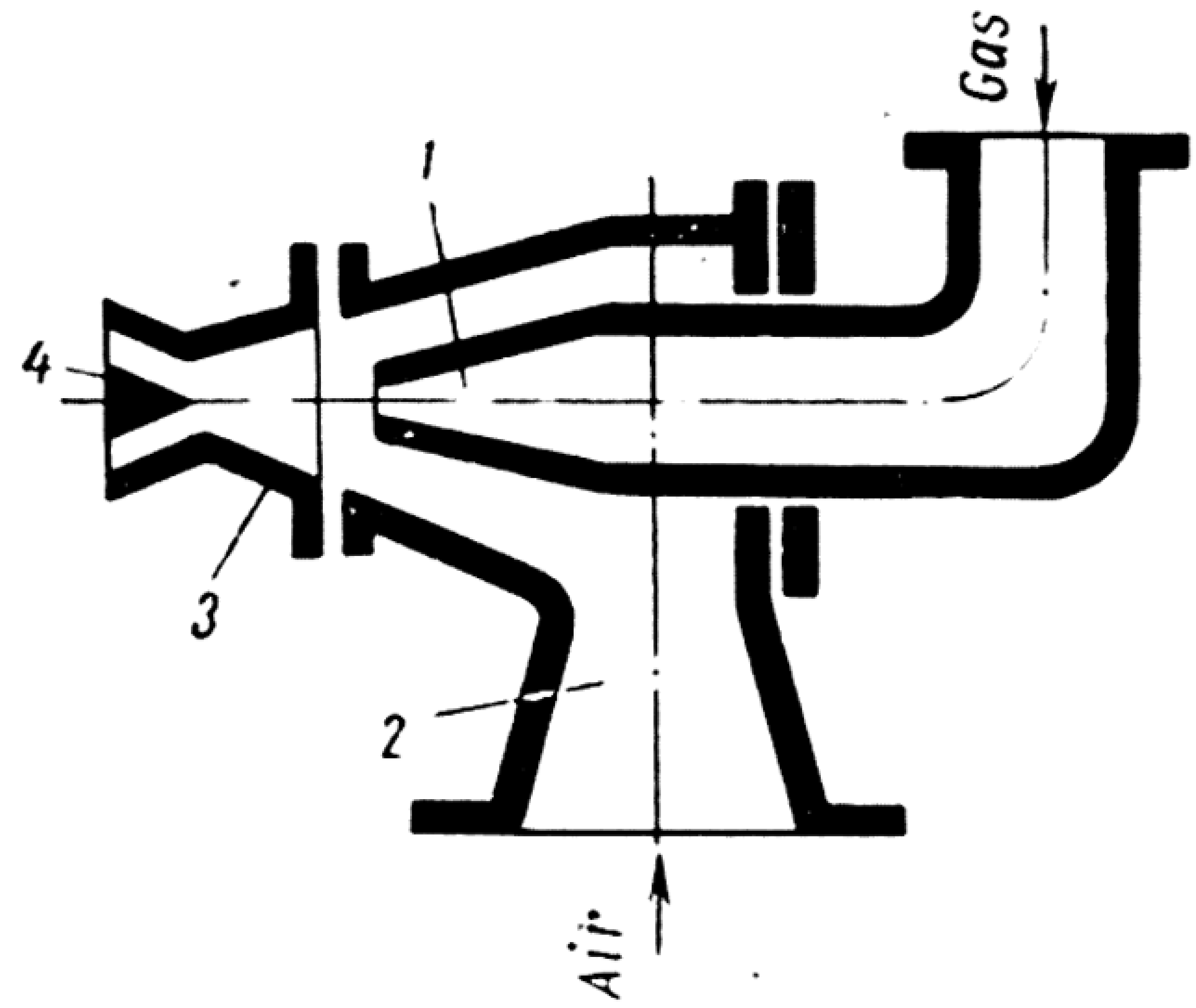


Fig. 33. Slot-type low-pressure burner

Fig. 33 shows a *slot-type burner*. Gas flows along tube *1*, and air—along tube *2*. The nozzles of tubes *1* and *2* and tip *3* are of rectangular cross-section. A special cone *4* is inserted inside tip *3*, to ensure better mixing of the gas and air. This burner produces a rectangular flame from 500 to 600 mm long.

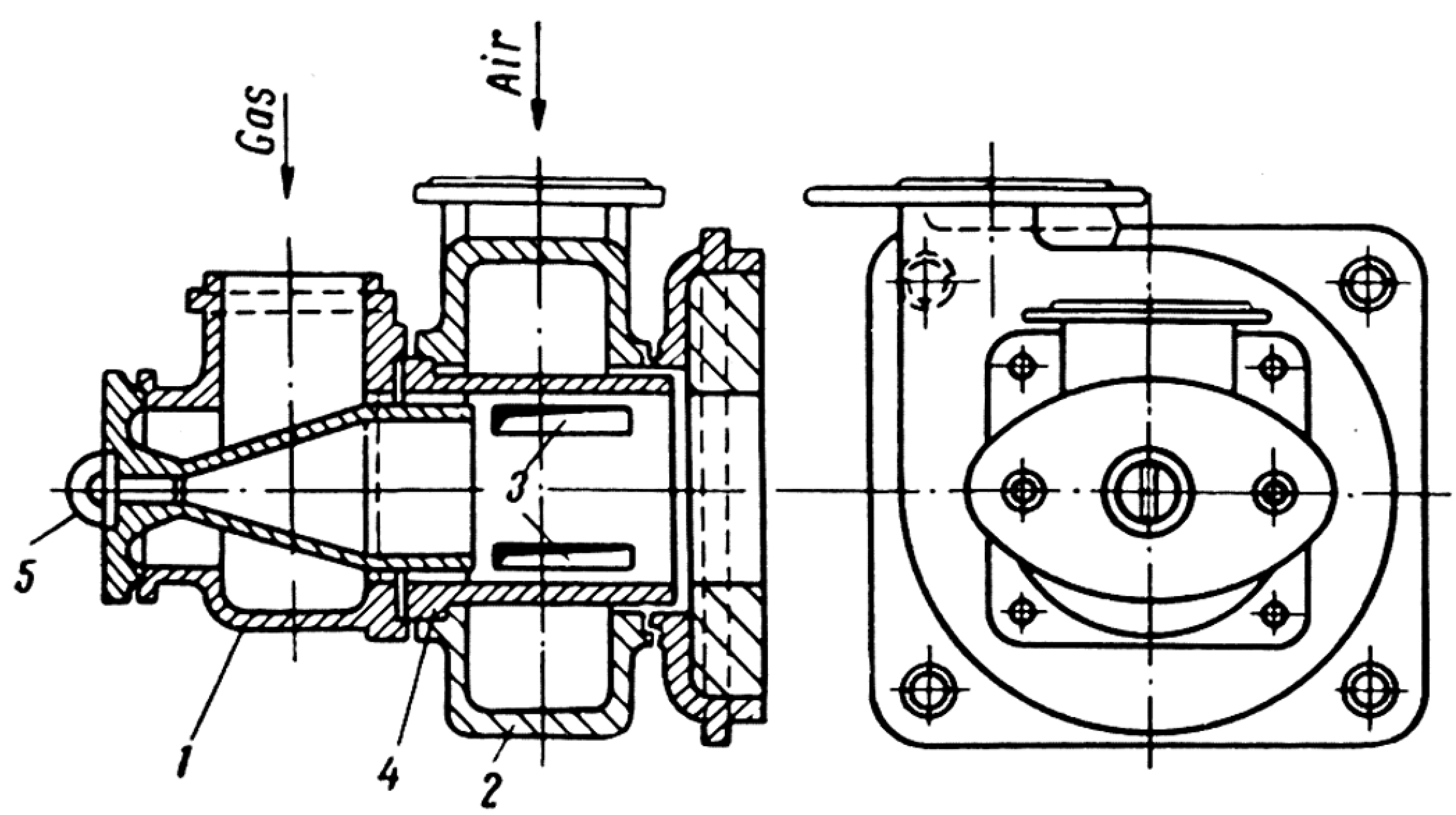


Fig. 34. Turbulent mixing burner:
1) gas chest; 2) air chest; 3) air admission port; 4) gas pipe; 5) plug; 6) gas; 7) air

Fig. 34 shows a *turbulent-mixing-type burner*, widely employed in the Soviet Union. This burner ensures a thorough mixing of the air and gas, a short flame and the possibility of regulating the output of the furnace within a considerable range.

PREPARING AND BURNING PULVERISED FUELS

At the present time pulverised fuels are used on an ever-increasing scale for firing heating furnaces and, in particular, for firing forge furnaces. There are many forge shops in the Soviet Union where all furnaces are fired exclusively with pulverised fuel. Pulverised fuel is particularly advantageous in plants where gas is not available, and which are supplied with local solid fuels (coal) which cannot be gasified. These fuels, when burnt in ordinary fire-boxes on grates, cannot ensure the necessary temperature for heating steel before forging.

The operation of furnaces fired with pulverised fuel can be compared with that of masout-fired furnaces. The chief advantages of burning pulverised coal as compared with the usual method of burning lump coal on grates, accompanied by manual servicing, are:

1. Pulverised coal, like masout or gas, is burnt in the working chamber of the furnace and therefore the high temperature above the metal being heated ensures its more rapid heating. When burning lump coal the highest temperature will be in the fire-box, i. e., at a great distance from the metal being heated.

2. When burning lump coal the metal in the working chamber of the furnace will be heated by the hot gases produced by the combustion of the coal in the fire-box. In furnaces fired with pulverised fuel, the metal is heated directly by the flame from the pulverised coal. In this case the metal will be heated better and more rapidly than by the hot gases.

3. In manually operated fire-boxes equipped with grates, a considerable amount—up to 10 per cent—of the fuel is lost together with the slag; on the other hand only a slight amount of fuel is lost with the slag when employing pulverised fuel. This permits a reduction in the consumption of fuel required for heating steel.

4. The use of pulverised fuel for firing furnaces cuts out the arduous work of stokers and ash-cleaners. There is no need to deliver coal to the shop and to carry away ashes. This, in turn, lightens the work of the factory transport system and frees large coal storage areas in shops. The pulverised coal is supplied to the furnaces along special pulverised fuel pipelines.

5. The temperature and thermal conditions of the furnaces can be easily controlled, as in masout-fired furnaces, inasmuch as pulverised fuel is burnt in burners with a wide range of efficiency.

6. The use of pulverised coal permits the employment of low-calorie coals which, when burnt in the usual way (as lump coal), do not ensure the requisite temperature for heating steel for forging. Moreover, screenings, i. e., coal fines which in practice cannot be burnt in ordinary manually operated fire-boxes can be utilised for making pulverised coal.

The maximum ash content of coals utilised as pulverised fuel for firing forge furnaces must be 15-20 per cent, and that of volatiles—not less than 20 per cent. The lower the ash content, the better will the pulverised coal burn. An important factor which must be considered when utilising pulverised fuel is the *fusion temperature of its ashes*. The most suitable coals are those with high-fusion ash content (i. e., whose ashes fuse at temperatures above 1,300°C). In practice, however, low-fusion ash pulverised coals are used for heating furnaces, but the method of burning such pulverised coals is different from that employed with high-fusion ash pulverised coals.

When burning pulverised coal above the surface of the heated steel, i. e., in the working chamber of the furnace, a portion of the dry ashes is precipitated on to the surface of the steel and some are carried away through the smoke flue. The ashes must be removed from the stock when it is taken out of the furnace, prior to forging or stamping, in order to exclude any possibility of their being pressed into the metal. It is easy to remove these ashes from the surface of light work, as low-fusion ashes and slag fall off its surface when the work is struck lightly against a piece of steel. It is more difficult, however, to remove ashes and particularly slag from heated heavy work. For this reason, when heating heavy pieces of stock, different methods are employed for burning pulverised coal, depending on the fusion temperature of the ash; these are:

1) Pulverised coal with a high-fusion ash content, i. e., the ashes of which fuse at temperatures above 1,300°C, is burned above the surface of the stock being heated, i. e., inside the working chamber of the furnace, in the same way as masout or gas; the dry ashes are precipitated on the surface of the work and can be easily removed before forging;

2) Pulverised coal with a low-fusion ash content, i. e., the ashes of which fuse at temperatures below 1,300°C, is burned in specially built fire-boxes. At temperatures above that of the fusion of the ashes, the latter, transformed into drops of liquid slag, become heavy, lose their volatile properties and are precipitated inside the fire-box. They are removed from here in the liquid state.

The second important factor which determines the choice of coals to be used for pulverised fuel is their *content of volatile substances*. The greater the content of volatiles, the better will the pulverised coal burn and the shorter its flame will be. The content of volatiles

in pulverised coal should be not less than 17-20 per cent; and pulverised coal with a content of volatiles up to 35 per cent may be regarded as an excellent fuel. Pulverised coal containing less than 17 per cent of volatiles will burn with an erratic flame, which tends to go out very frequently, causing the furnace to operate irregularly.

Coals from the Kuznetsk Basin are considered excellent for preparing pulverised fuel. Pulverised coke and anthracite are not

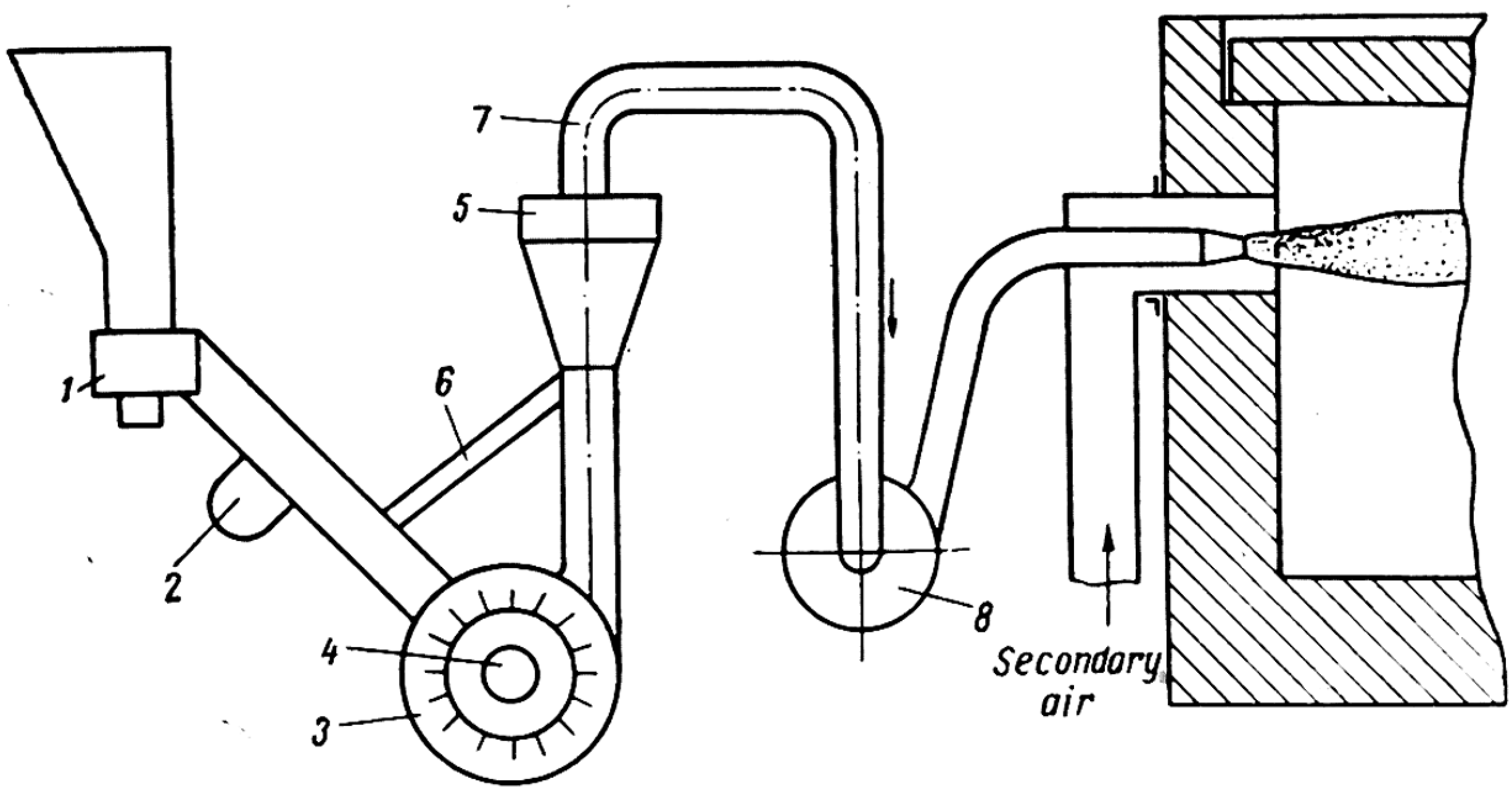


Fig. 35. Individual pulverising unit

suitable for firing heating furnaces, as they have a low content of volatiles.

Before coal can be burnt in the pulverised state, it must be ground in special installations to a fineness of 0.07 to 0.05 mm. Pulverised coal is prepared in individual units supplying one or more furnaces or in a centralised installation supplying one or several shops. Fig. 35 illustrates the simplest individual *coal pulverising unit*.

From a special hopper the coal is fed through feeder *1*, which ensures a uniform delivery of the coal, to magnet separator *2* in which it is freed from any pieces of iron or steel which it may contain. From the separator the coal is delivered to mill *3* where it is ground and dried by hot air supplied to the mill through pipe *4*. The ground coal, in the form of dust, is carried by the hot air from the mill into cyclone separator *5*, where it is finally dried. In the cyclone separator the large lumps of coal are separated from the coal dust and are returned to mill *3* along pipe *6*. The coal, ground to the requisite fineness, is delivered through ground-coal duct *7* to centrifugal coal-dust fan *8*. Here, after being mixed with air (the so-called preliminary air) it is blown into the furnace.

Pulverised coal is burnt with the aid of *special burners* in the same way as masout or gas.

Several types of burners are employed for burning pulverised coal. Fig. 36 shows a burner employed for heating furnaces. It con-

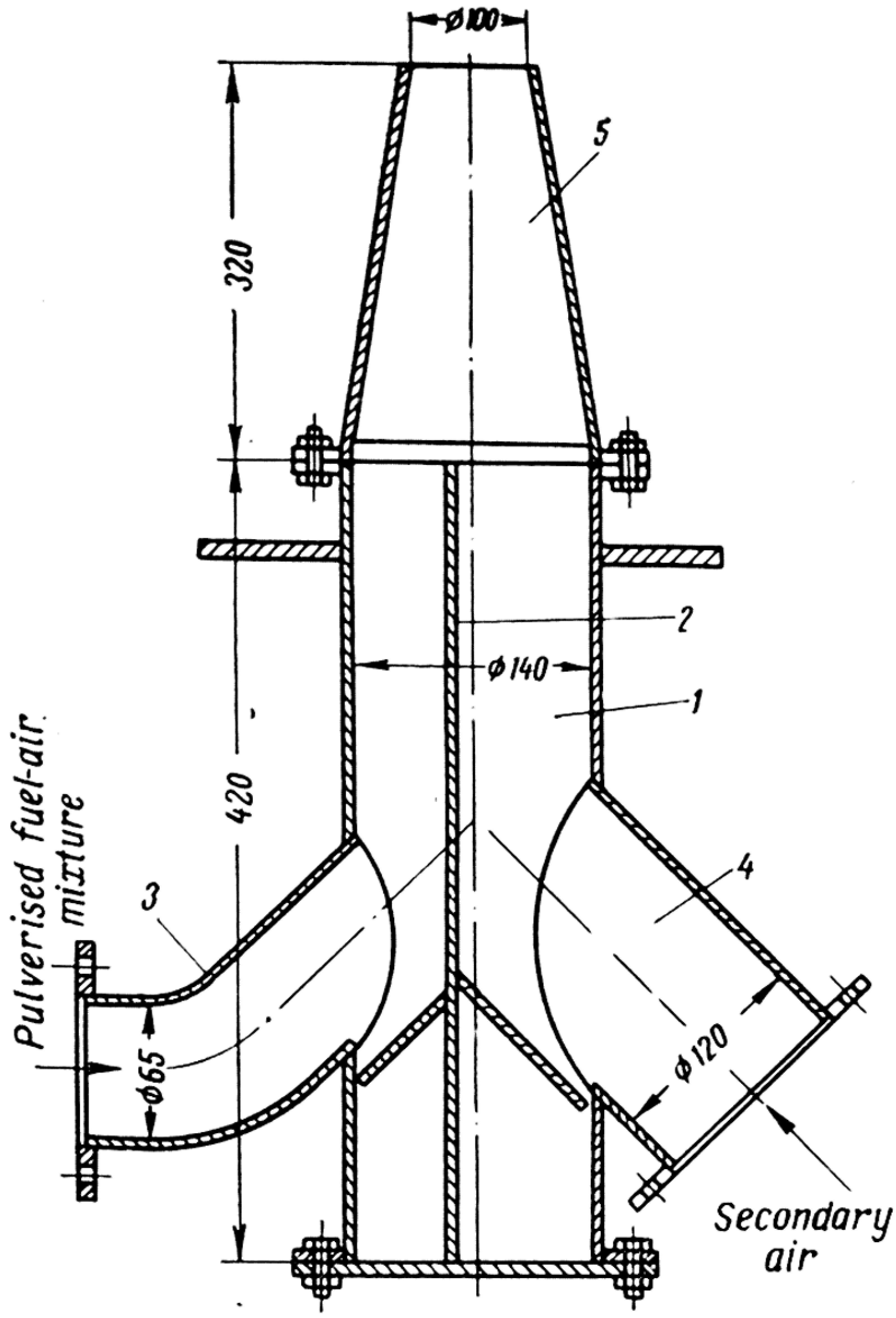


Fig. 36. Special burner for burning pulverised coal

sists of tube *1*, divided by partition *2*. The mixture of air and pulverised coal flows along tube *3*, and secondary air—from the fan, along tube *4*. The pulverised coal is mixed with the secondary air at its discharge from nozzle *5* and ignites at a certain distance from the nozzle inside the working chamber of the furnace.

CHAPTER IV

HEATING DEVICES

BLACKSMITH'S HEARTHS

Blacksmith's hearths, or forges, as they are also called, are employed for heating metals for hand forging. These forges are classified either as *open* or *closed* hearths. Blacksmith's forges have one or two hearths, and are correspondingly called single- or double-hearth blacksmith's forges (Fig. 37).

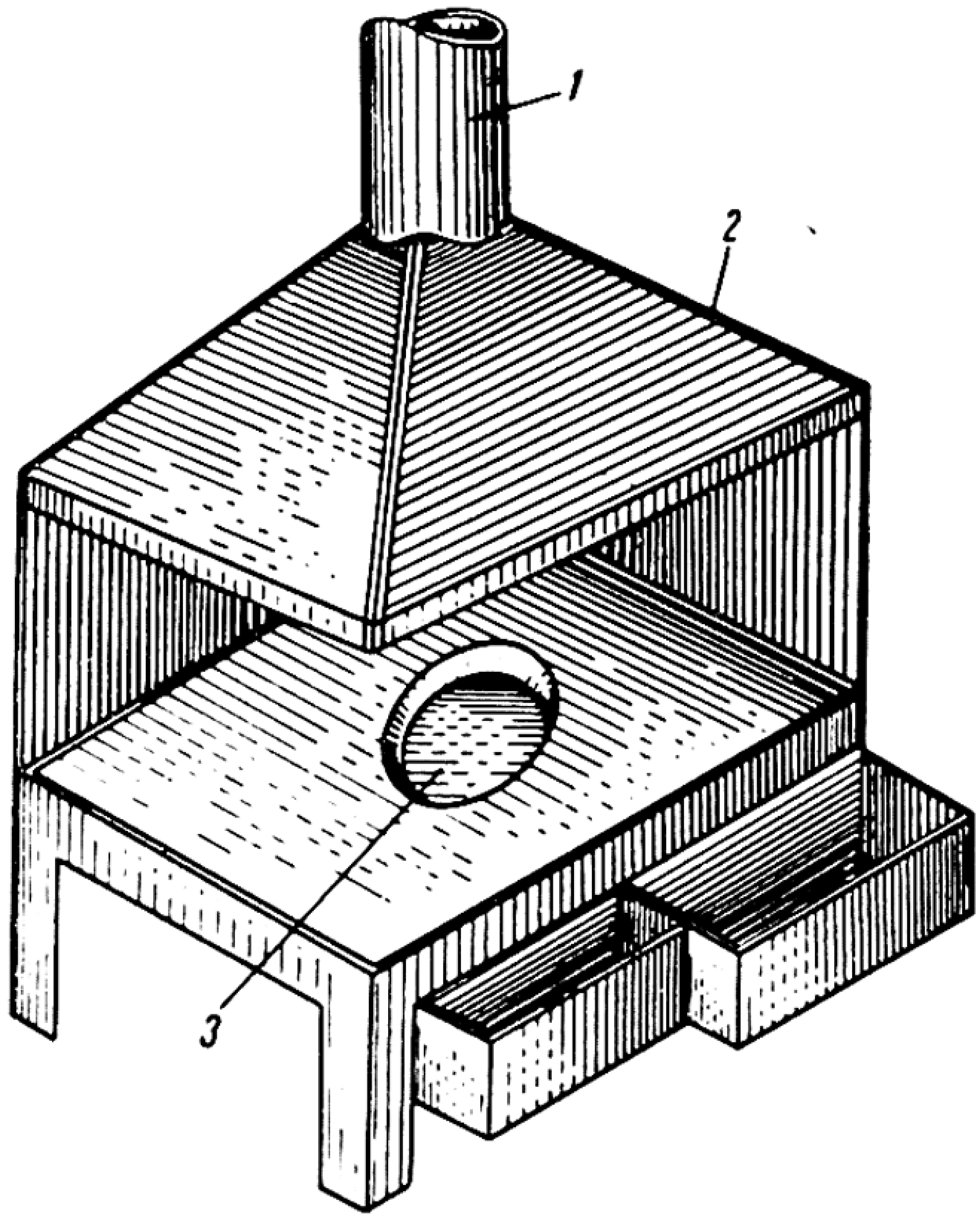


Fig. 37. Single-hearth blacksmith's forge:
1) chimney; 2) hood; 3) tuyere (hearth for burning fuel)

The air necessary for burning the fuel is fed downwards from a fan along a pipe. The air pressure (blast) at the hearth should be from 150 to 200 mm water column. The lower end of the air pipe ends in what is called a tuyere (Fig. 38). The tuyere is equipped with a hole for raking out the ashes and slag. A hood is installed above the hearth for collecting the products of combustion, which are discharged into the atmosphere through a chimney from the hood.

The method of gathering the smoke in the hood and discharging it subsequently through the chimney by means of natural draught is not efficient. When firing the hearth the smoke, instead of entering the hood, spreads throughout the shop. Such a blacksmith's hearth is shown in Fig. 37. Fig. 39 shows an *open blacksmith's hearth* with a different method of discharging the smoke from that shown in Fig. 37. In this hearth the smoke is discharged through two pipes *1* and *2*,

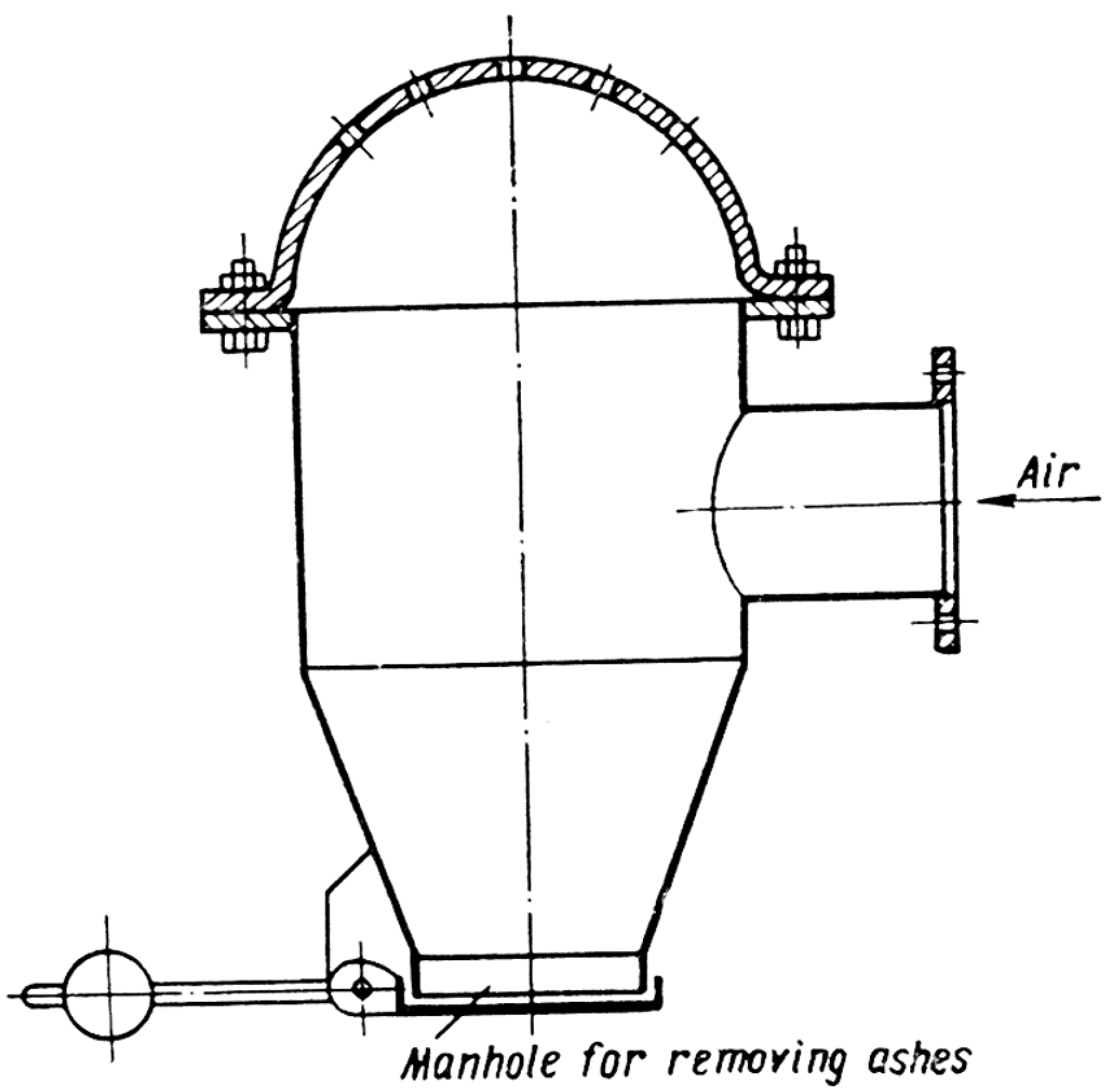


Fig. 38. Tuyere of a blacksmith's hearth

pipe *1* being inserted inside pipe *2*. Part of the smoke escapes through inner pipe *1* and the remainder, entering hood *3*, escapes through outer pipe *2*. In such an arrangement, the inner smoke pipe, or chimney, is heated by the outer, and the draught is increased. Such chimneys have proved their efficiency in practice.

Fig. 40 shows a *closed blacksmith's forge*. It consists of a steel framework lined with refractory brick.

The air (blast) is delivered through pipe *1* into chest *2* whence it enters the firebox through grate *3*. The coal is charged through firing opening *4*, and the steel to be heated through charging door *5*. The products of combustion are discharged from the hearth through outlet *6* under hood *7*. Secondary air is fed into the upper part of the hearth through pipes *8* to ensure the complete combustion of the volatiles.

Closed blacksmith's hearths are employed in mass production for heating small parts.

Masout is utilised in liquid fuel-fired blacksmith's hearths. An important feature of such hearths is the *combustion chamber* (see Fig. 41). Masout is fed through funnel *7* and pipe *8* into chamber *9*; air—through inlet *1*, chamber *2*, outlets *5* and *6*. From chamber *9* masout flows in thin streams along inclined plane *11*. Caught up by streams of air leaving outlet *5*, it is atomised and burnt. The masout which fails to be atomised, drops down, is caught up by the stream of air leaving outlet *6* and is also atomised and burnt.

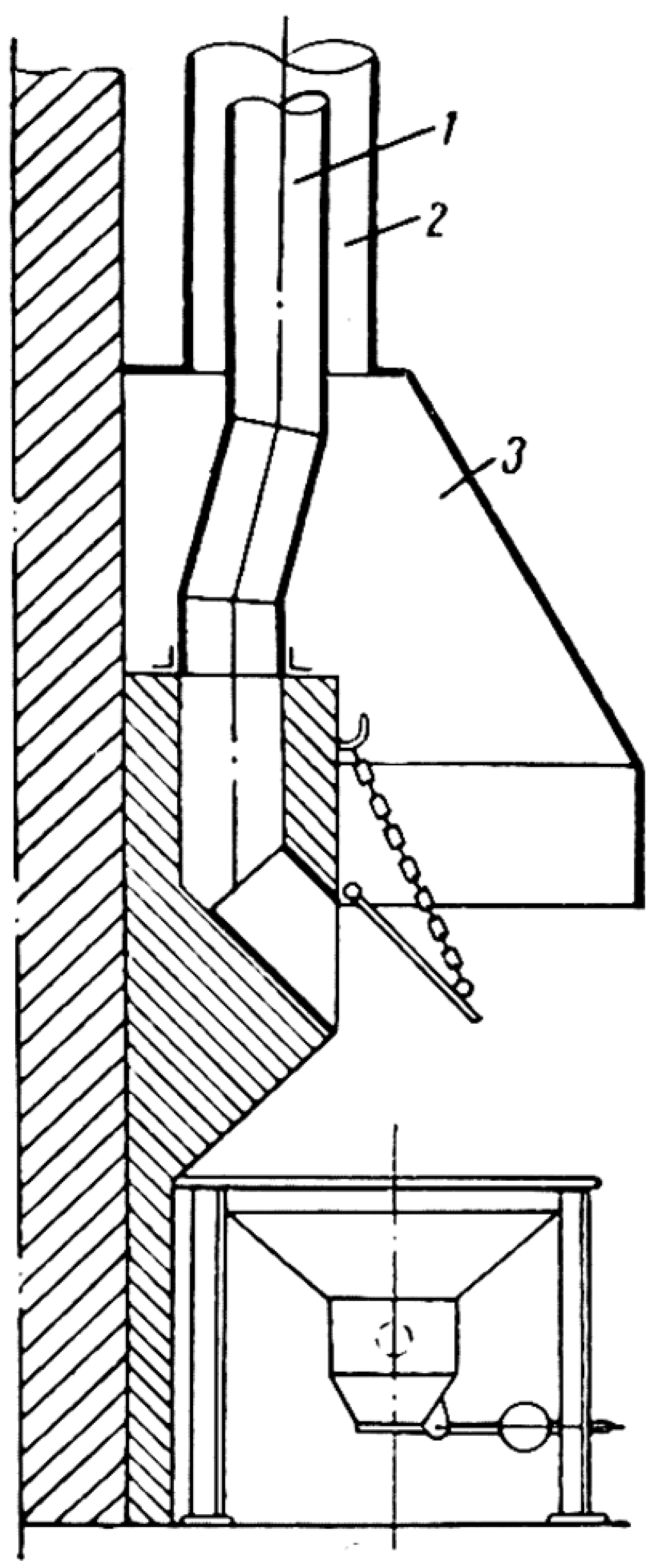


Fig. 39. Open blacksmith's hearth

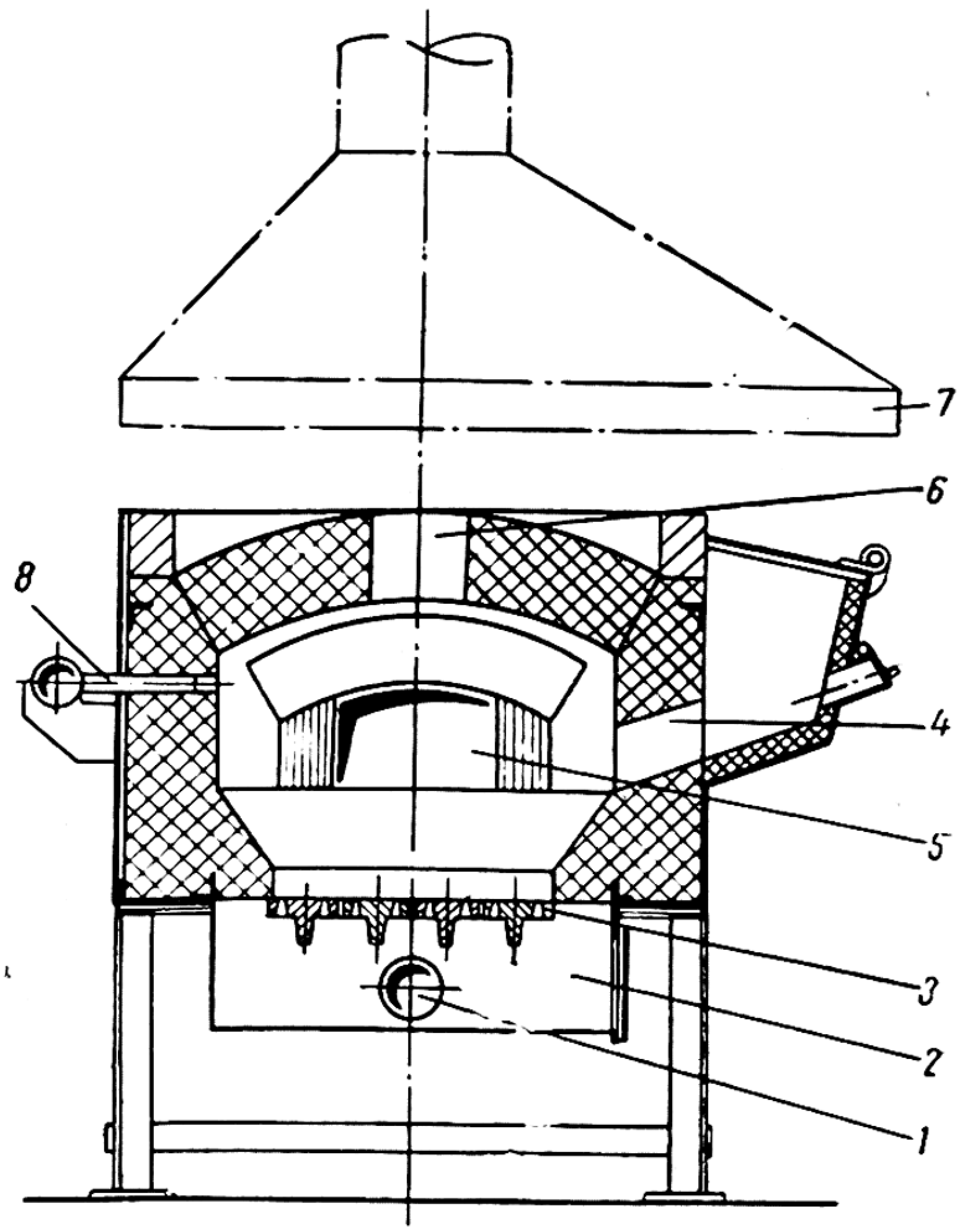


Fig. 40. Closed blacksmith's hearth

The masout is thus mixed with air and burns in combustion chamber *3*, which is built with fire-clay lined walls *4* and *10*. The temperature in the combustion chamber is very high and reaches white heat. Gas enters the hearth through outlet *12*, shown in Fig. 42. The combustion chamber is shown to the right of the circular hearth. Forgings placed in the hearth are heated by the gases discharged from the combustion chamber.

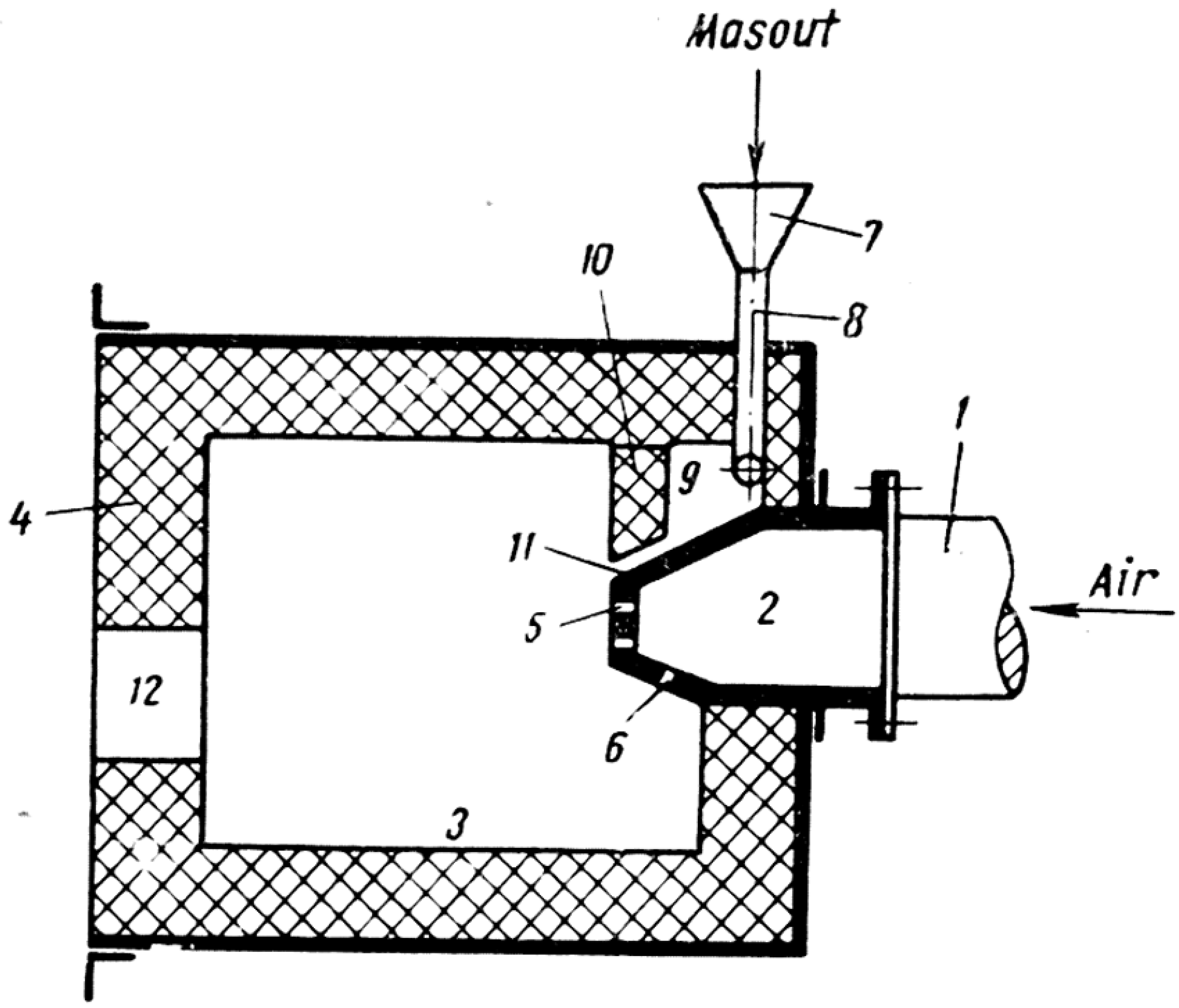


Fig. 41. Combustion chamber of masout-fired blacksmith's hearth

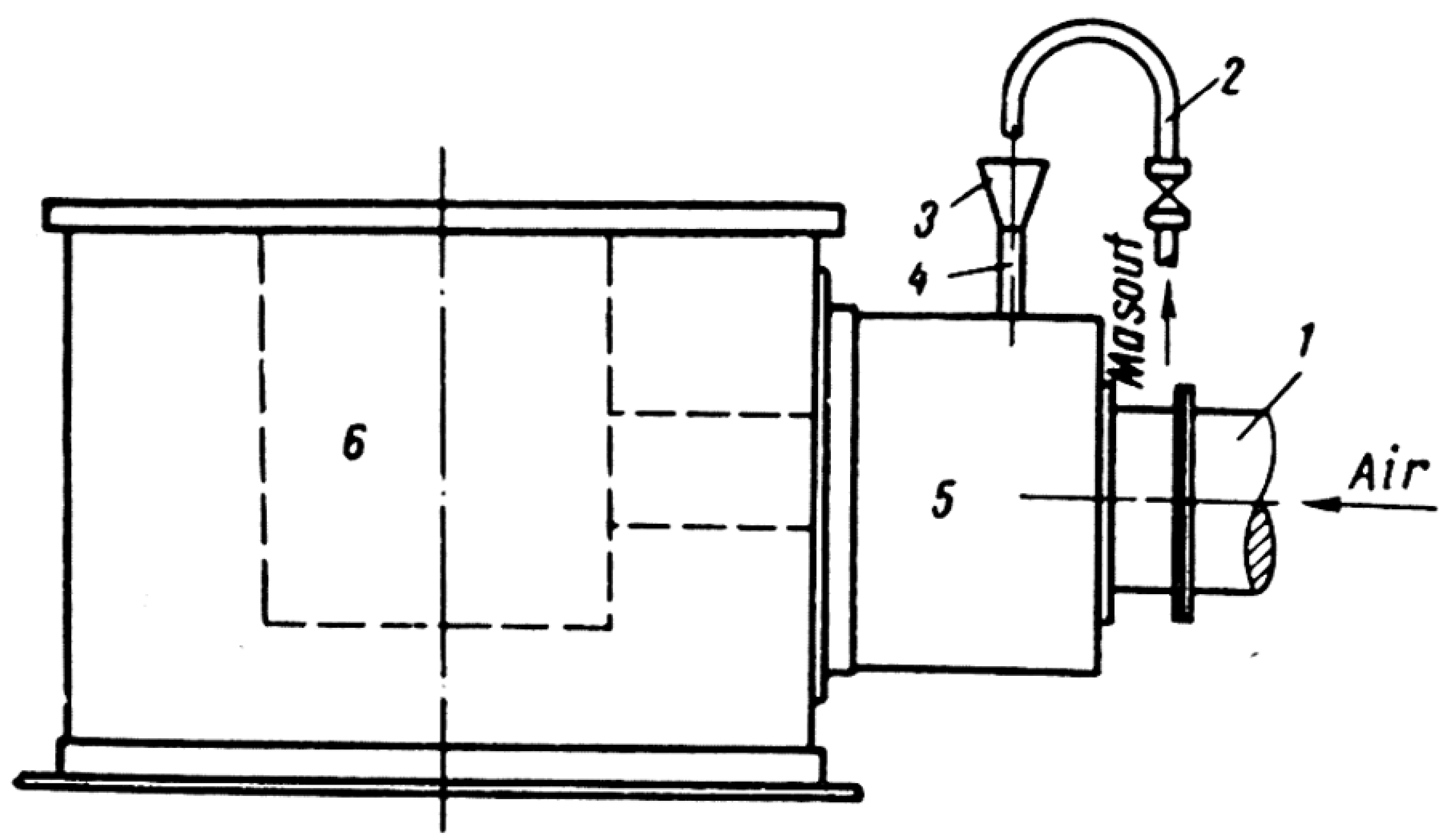


Fig. 42. Masout-fired blacksmith's hearth:
1) air line; 2) masout line; 3) funnel; 4) pipe; 5) combustion chamber; 6) hearth (heating chamber); 7) masout inlet; 8) air inlet

Gas-fired hearths are employed for heating the ends of stock. The rotating gas-fired blacksmith's hearth, shown in Fig. 43, is cylindrical in shape and is mounted on ball supports *4*. In this hearth the stock to be heated is charged into holes *1*, arranged in its wall. The mixture of gas and air is fed to the burner *2*, and ignited. To ensure a more rapid heating of the work, the hearth is lined with a fire-proof cone *3*. Flue gases are discharged directly into the shop through holes *1*. In gas-fired hearths, stock can be heated up to 1,250-1,280° C.

The main disadvantages of blacksmith's hearths fired by ordinary coal are:

1. The steel comes into direct contact with the fuel, which always contains sulphur. At high temperatures, sulphur is absorbed by the steel and thus lowers its mechanical properties. Because of this,

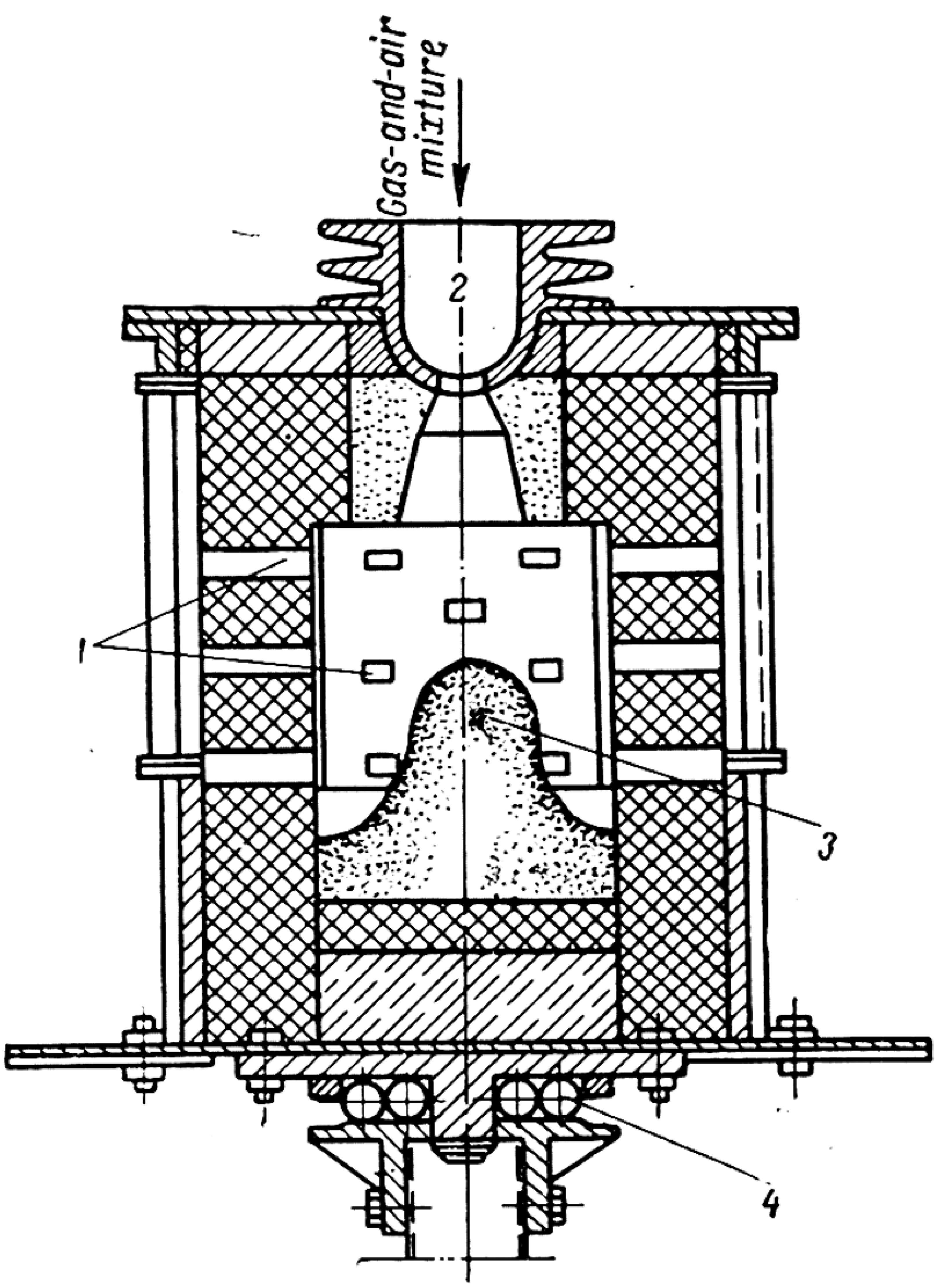


Fig. 43. Rotating gas-fired blacksmith's hearth:
1) stock charging opening; 2) burner; 3) refractory cone; 4) ball support for installing hearth 5) gas-and-air mixture

blacksmith's hearths should be fired with special coal having a minimum sulphur content. The steel must be placed in these hearths only after the coal has begun to burn properly and the sulphur has been burnt out.

2. There is a danger of the steel being heated coming into direct contact with the blast of air, thereby entailing a considerable loss of metal as scale.

3. In these hearths the heating of the steel is not uniform; the coal does not completely burn up, and part of it is thrown out togeth-

er with the ashes. In addition, the products of combustion, heated to a high temperature, escape into the atmosphere and take with them a considerable quantity of heat.

These disadvantages result in a far greater consumption of fuel when heating steel in hearths, as compared to that consumed in furnaces: fuel consumption being from 40 to 150 per cent of the weight of the steel, with an accompanying loss of 8 per cent of the weight of steel as scale.

The advantages of the blacksmith's hearth consist in its simplicity and cheapness in manufacture. Moreover, any section of a long piece of work can be heated in an ordinary blacksmith's hearth, for instance, for bending purposes; this is not always possible in forge furnaces.

FUNDAMENTAL RULES FOR WORKING WITH BLACKSMITH'S HEARTHS

When heating a piece of steel in a hearth, the blacksmith must always watch the flame of the fuel. Metal is heated best of all in a bright, slightly smoking, flame: such a flame excludes all possibility of overheating the metal.

If the flame is blindingly bright, which occurs with an excess of air, a thick layer of *scale* will form on the surface of the steel, which will be in danger of *being burnt*. On the other hand, if clouds of dense black smoke continue to emerge from the hearth, the steel will be heated slowly, considerable coal will be consumed and the resulting temperature will be insufficient. A poorly heated piece of stock will be difficult to forge, and will be liable to crack. It follows that when heating a piece of steel in a blacksmith's hearth, it is necessary to maintain a bright, slightly smoking flame. In addition, the blacksmith must know how to place the stock in the hearth so that it is heated rapidly and uniformly all round.

The stock to be heated must be protected from being cooled by the air (the blast), and for this reason the bed of fuel under the work should be at least 100 mm thick. The work must also be covered with a layer of coal. To obtain a flame at a single spot, the coal should be slightly damped with water and pressed down with a shovel. In the spot where the flame is desired, the coal should be loosened with a poker. To ensure uniform heating of the work on all sides, it must be turned round from time to time.

To maintain a constant flame in the hearth during the entire shift, fresh coal should be added, not directly into the zone of combustion, but at the edge of the hearth and shovelled to the centre as it burns out.

The temperature of steel for hand forging is generally determined by the temper colour. The following table gives the *temper colours*, depending on the temperature, for steel:

Temper colour of steel	Temperature, degrees Centigrade	Temper colour of steel	Temperature, degrees Centigrade
Brown	500	Dark orange	900
Dark purple	550	Orange-yellow	1000
Dark red	650	Straw-yellow	1100
Cherry-red	700	Very light yellow	1200
Light cherry-red	800	White	1300
		Bright white	1400

Rules to be observed for maintaining a hearth. Before commencing work, always:

1) Remove all slag, remains of coal and pieces of brick from the hearth;

2) Remove all slag from the tuyere, and blow air through it;

3) See that the air line and the dampers are in good order. The damper must completely cut off all access of air;

4) Make a small fire in the hearth with wood shavings or burning coal taken from a hearth or furnace already in use, slightly open the damper on the air line; after the shavings have caught fire, gradually add coal and increase the blast.

During operation:

1) See that the flame in the hearth is uniform; avoid too strong a blast, otherwise pieces of coal will be thrown out of the fire;

2) See that the tuyere is always covered with a layer of coal, and that the blast air never comes in contact with the steel being heated;

3) See that the top layer of coal cakes properly to form a crust; periodically wet the top layer of coal with water to facilitate its caking;

4) See that the tuyere is not choked up with slag; it should be cleaned from time to time through the lower hole with the blast only slightly open.

After work, it is necessary to:

1) Close the air damper;

2) If the work is not handed over to the next shift, scrape the burnt coals off the hearth and extinguish the fire;

3) Put all tools, devices and forgings in their proper places;

4) Put your working place in order.

HEATING FURNACES

For hammer forging and sometimes for hand forging, stock is heated in flame furnaces. These furnaces are called *flame furnaces*, because the steel is heated by the flame produced from the combustion of the fuel.

Forge furnaces are built so as to ensure a temperature up to 1,350°C in their working chambers. Each heating furnace consists of the following parts: fire-box, working chamber, chimney, flues, recuperator or regenerator, and various auxiliary arrangements (Fig. 44).

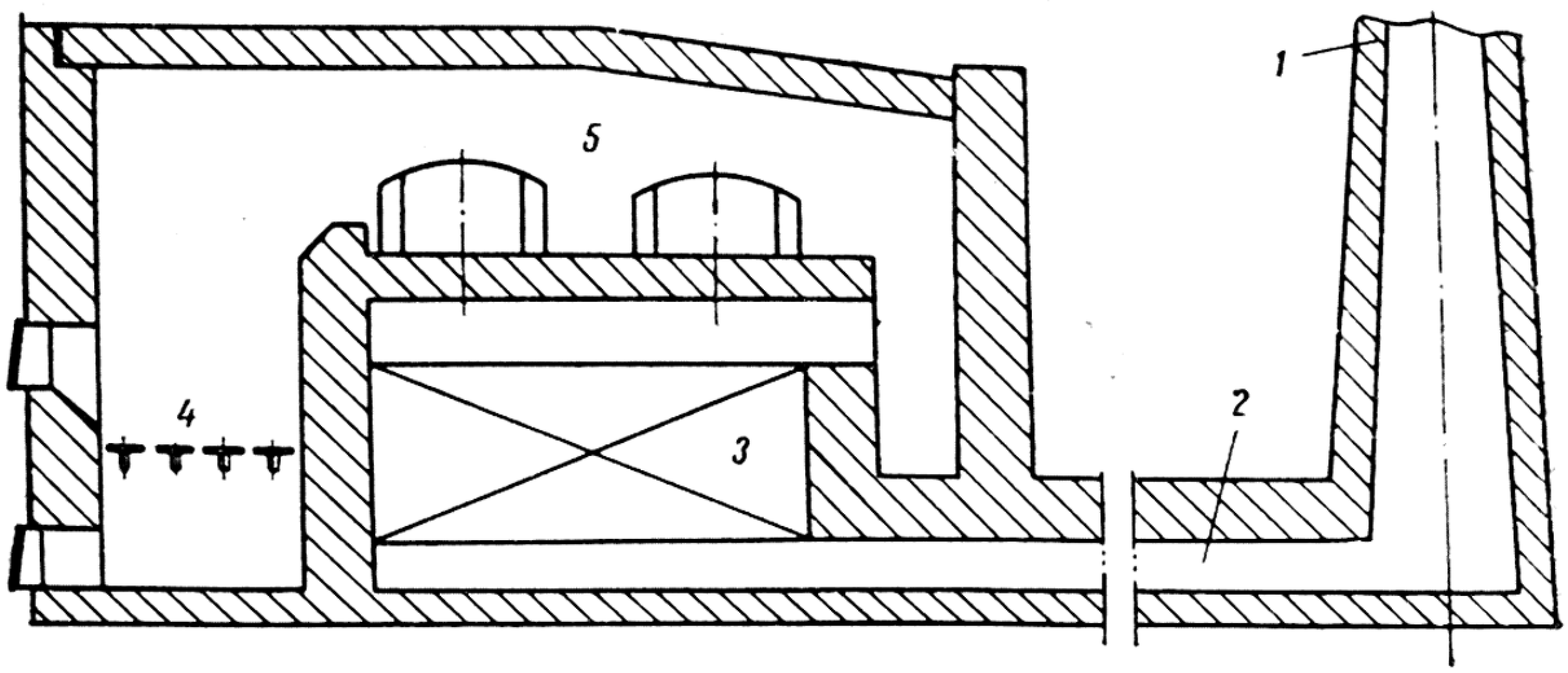


Fig. 44. The elements of a heating furnace:
1) chimney; 2) flue; 3) recuperator or regenerator; 4) fire-box; 5) working chamber

The *fire-box* of a furnace is that part in which the combustion of fuel takes place. The working chamber is that part in which the steel to be heated is placed. The lower section, or base of the working chamber, on which the steel is placed, is called the hearth; the upper part of the furnace is called its roof. The opening through which the metal is charged into the furnace is called the charging door, while the opening through which the metal is discharged from the furnace is called the discharging door.

The *flues* serve for discharging the flue gases from the furnace into the chimneys; the recuperators and regenerators are designed for preheating the air with the aid of the heat of the flue gases. The chimney serves to discharge the flue gases into the atmosphere.

FURNACE PRODUCTIVITY

By the productivity of a furnace is understood the weight of metal that can be heated in the furnace to the required forging temperature in any unit of time. As a rule, *furnace productivity* is expressed in

kilograms per hour, and depends on the dimensions of the stock being heated, the quality (grade) of the steel and the charging temperature, i. e., whether the steel is charged hot or cold into the furnace. The greater the capacity of the furnace and the less the time required for heating the stock, the greater its productivity will be.

By the capacity of a furnace is understood the weight of metal that can be loaded into the furnace at one time. The *capacity of a furnace* should never be increased by loading it with stock stacked in several layers, one on top of each other, as this will only lower and not increase its productivity. Moreover, stacking the stock on the hearth in several layers can result in uneven heating and an increase in the loss of steel as scale. To increase the productivity of a furnace, it is necessary to:

1. Place the stock on the furnace hearth in such a way as to ensure the complete utilisation of the hearth area and, at the same time, to ensure that the stock is "licked" on all sides by the hot gases.

2. Charge the stock into and discharge it from the furnace continuously and at a uniform speed, taking care that it is never held too long in the high temperature zone. The best charging and discharging method is the single-piece method, whereby one or two pieces of stock are unloaded from the furnace, their place being taken by cold pieces of stock.

3. Maintain the working chamber of the furnace at a temperature from 100° to 150°C above the steel heating temperature. For instance, should the technological process call for heating the steel to 1,200°C, the temperature of the working chamber of the furnace should be $1{,}200+(100 \text{ to } 150)=1{,}300 \text{ to } 1{,}350$°C.

The operation of furnaces, in which approximately similar pieces of work are heated, is compared by what is known as the specific productivity, or load rate on the hearth, of a furnace. By the *specific productivity of a furnace* or the load rate on the hearth is understood the weight of metal heated to a preset temperature per square metre of hearth area per unit of time—usually, per hour, and is expressed as $kg/m^2/hr$. In other words, the specific productivity of a furnace is determined by dividing its hourly productivity by the area of its hearth.

FURNACE EFFICIENCY

The index of the utilisation of heat in a furnace is called its *efficiency*, which indicates that proportion of heat generated by the combustion of fuel which is actually utilised for heating the metal.

The *utilisation of the heat* generated by the combustion of fuel can be considered as follows (see Fig. 45). If we take the total amount of heat generated as 100 per cent, then: a) the amount of heat utilised for heating a piece of metal A_1 will be from 10 to 15 per cent of the total amount of heat generated; b) the heat loss A_2 through charging openings and slots will fluctuate between 10 and 15 per cent depending on the design of the furnace, the dimensions and numbers of the slots and charging openings; c) the heat losses A_3 due to incomplete combustion will vary from 0.5 to 1 per cent; d) the heat losses A_4 through the furnace brickwork will reach 25 per cent; e) the loss of heat A_5, escaping with the flue gases, will amount to 45-50 per cent.

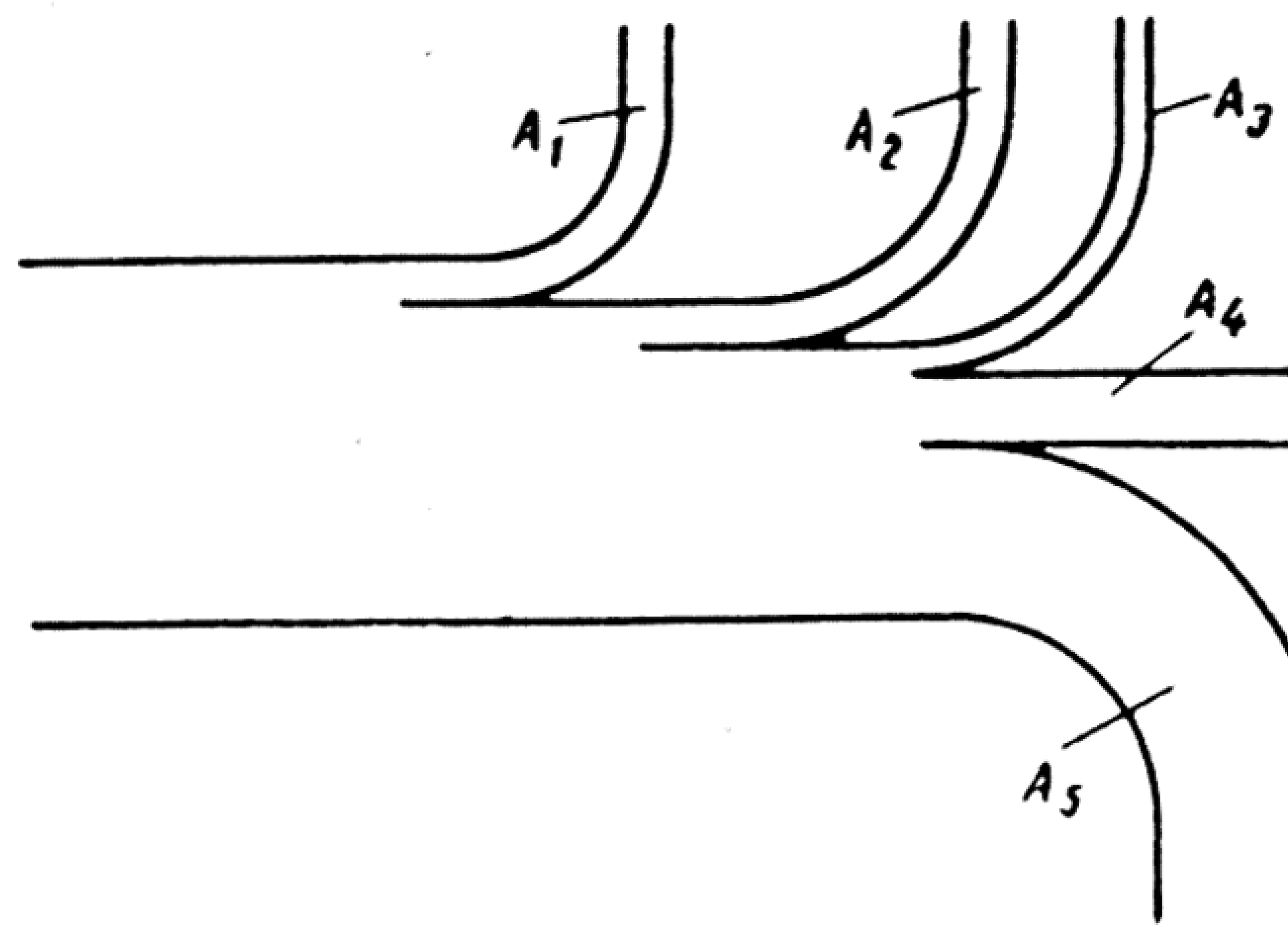


Fig. 45. Scheme of utilisation of heat in furnace

Thus, only from 10 to 15 per cent of the total heat will be usefully expended, i. e., will be utilised for heating the metal; the remainder—from 85 to 90 per cent—is lost.

It is this relation between the amount of utilised heat and the total amount of heat delivered to the furnace which is called the efficiency of the furnace. Furnace efficiency is always expressed as a percentage. If we express the total amount of heat delivered to the furnace as (A Cal/hr), and the utilised heat as (a Cal/hr), the efficiency of the furnace will be equal to:

$$\frac{a}{A}100\%.$$

The higher the furnace efficiency, the less heat will be consumed for heating a unit weight of metal.

The economy of the operation of similar type furnaces employed for heating approximately similar pieces of work is measured by comparing the so-called *specific consumption of conventional fuel*. The specific consumption of conventional fuel is that amount of conventional fuel, expressed in per cent or in kilograms per weight of heated metal, which is consumed by the furnace for heating the metal in a unit of time.

Example. The productivity of a furnace A=2,000 kg per hour. It consumes 250 kg per hour of coal having a calorific value of 5,600 large calories per hour. Determine its specific consumption of conventional fuel.

Solution. The calorific value of conventional fuel is 7,000 Cal. Therefore, the consumption of conventional fuel will be:

$$B=\frac{250\times 5,600}{7,000}=200 \text{ kg per hour.}$$

The specific consumption of conventional fuel, in percentage of heated metal, will be:

$$b=\frac{B\times 100}{2,000}=\frac{200\times 100}{2,000}=10\%.$$

The specific consumption of conventional fuels in forge furnaces usually ranges from 8 to 12 per cent of the weight of steel being heated.

UTILISATION OF THE HEAT OF THE WASTE PRODUCTS OF COMBUSTION

In all industrial furnaces, including forge furnaces, the main heat losses consist of the heat escaping from the furnaces together with the products of combustion (smoke). It is for this reason necessary to utilise this heat as much as possible. One of the most common methods of making use of the heat of the products of combustion is to employ it for preheating the air to a temperature of 200-500°C and over. After being preheated, the air enters the furnace for burning the fuel, i. e., it is delivered beneath the grate or directed to the burners. The heat extracted from the escaping products of combustion is returned to the furnace together with the heated air, thereby increas-

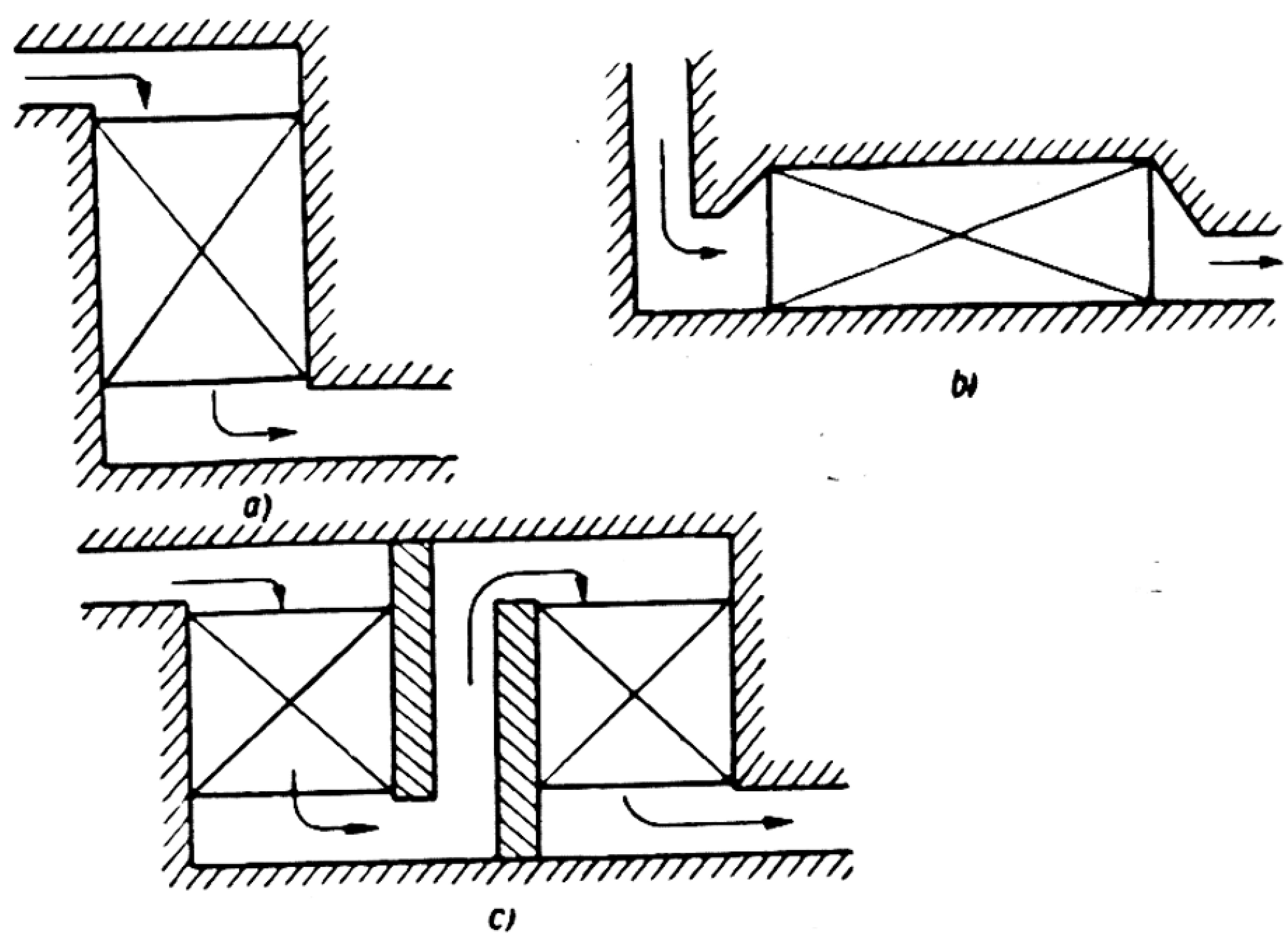


Fig. 46. Schematic representation of a regenerator:
a) vertical regenerator; b) horizontal regenerator; c) zig-zag-type regenerator

ing the furnace's efficiency (reducing the fuel consumption) and increasing the temperature of the combustion of the fuel and, consequently, the productivity of the furnace.

There are two methods of using the escaping products of combustion to heat air. By the first method the air is heated in *regenerators*; by the second, in *recuperators.*

The schematic arrangement of a regenerator is shown in Fig. 46. Regenerators are made in the form of brick chambers loosely packed with a checker-work of refractory bricks so as to form a multitude of channels. Fig. 47 shows the checker-work of a regenerator arranged to form a mass of channels.

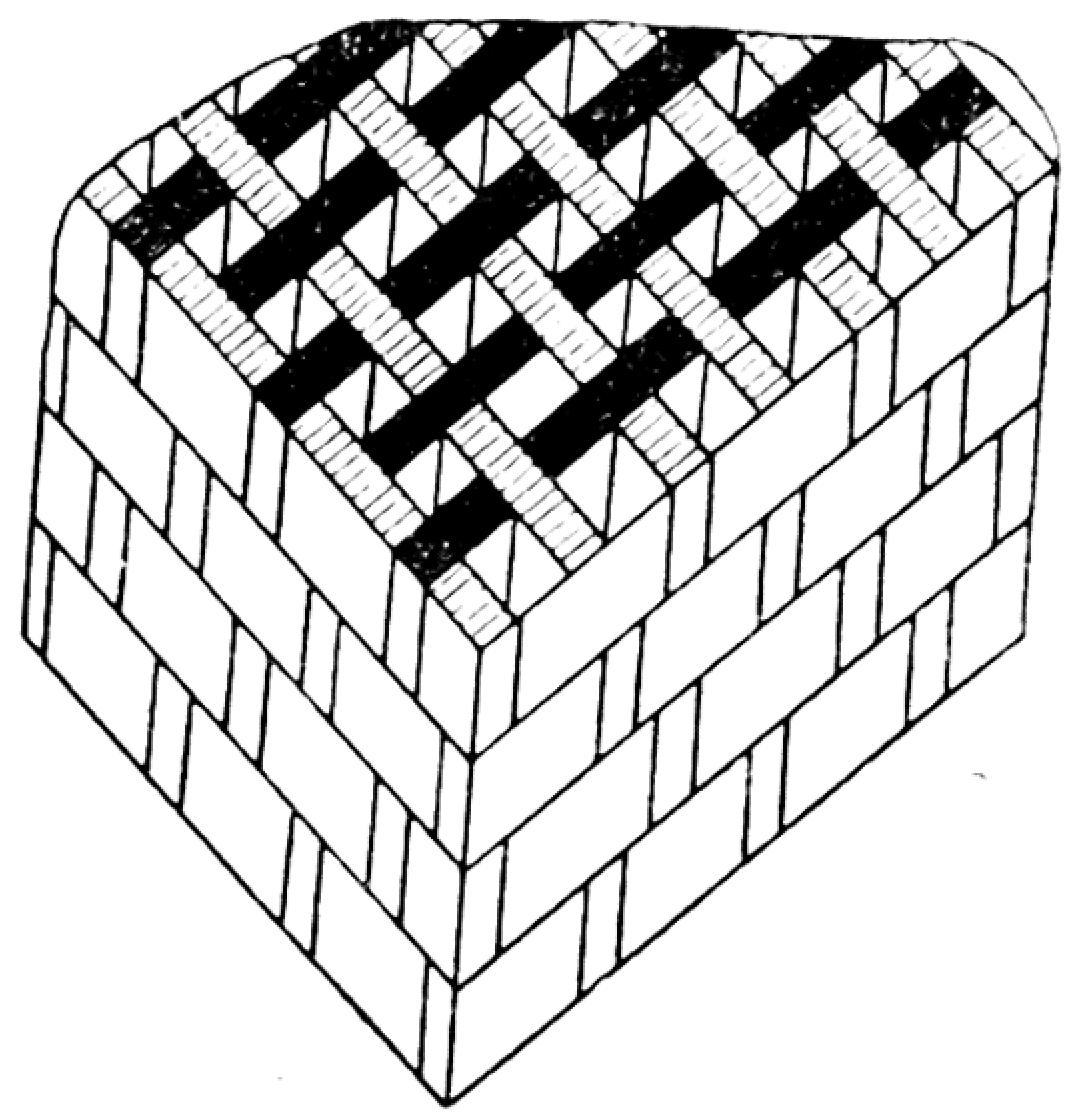


Fig. 47. Regenerator checker-work

Regenerators operate as follows: hot waste products of combustion are first directed through the channels of the checker-work, thus heating its refractory brickwork. After this checker-work has become sufficiently hot, the delivery of the products of combustion is cut off and the gases are directed to the second regenerator, which is located next to the first. Meanwhile, cold air is passed through the checker-work of the first; the cold air, coming into contact with the hot checker-work, becomes heated and is then delivered to the furnace for burning the fuel.

Regenerators thus operate by alternately heating the air, and being heated. Therefore at least two regenerators are required for each furnace in order to ensure a continuous supply of hot air to the furnace. In one regenerator the air will be heated, while the hot products of combustion will be flowing from the furnace to the second regenerator, where they will be heating the checker-work. Regenerators permit the heating of air or gases to higher temperatures than do recuperators, but are bulky and expensive installations. Nowadays they are employed only for large furnaces fired with poor gases; in this case, in order to ensure the temperature required for heating the metal, the air is heated to a high temperature.

Recuperators operating on the principle of the transmission of heat through their walls are in wide use at the present time. There are two types of *recuperators*—ceramic and metallic. Ceramic recuperators are built of shaped refractory brick. Their chief advantages compared with metallic recuperators are that they are very durable, can be employed for heating air to high temperatures and have

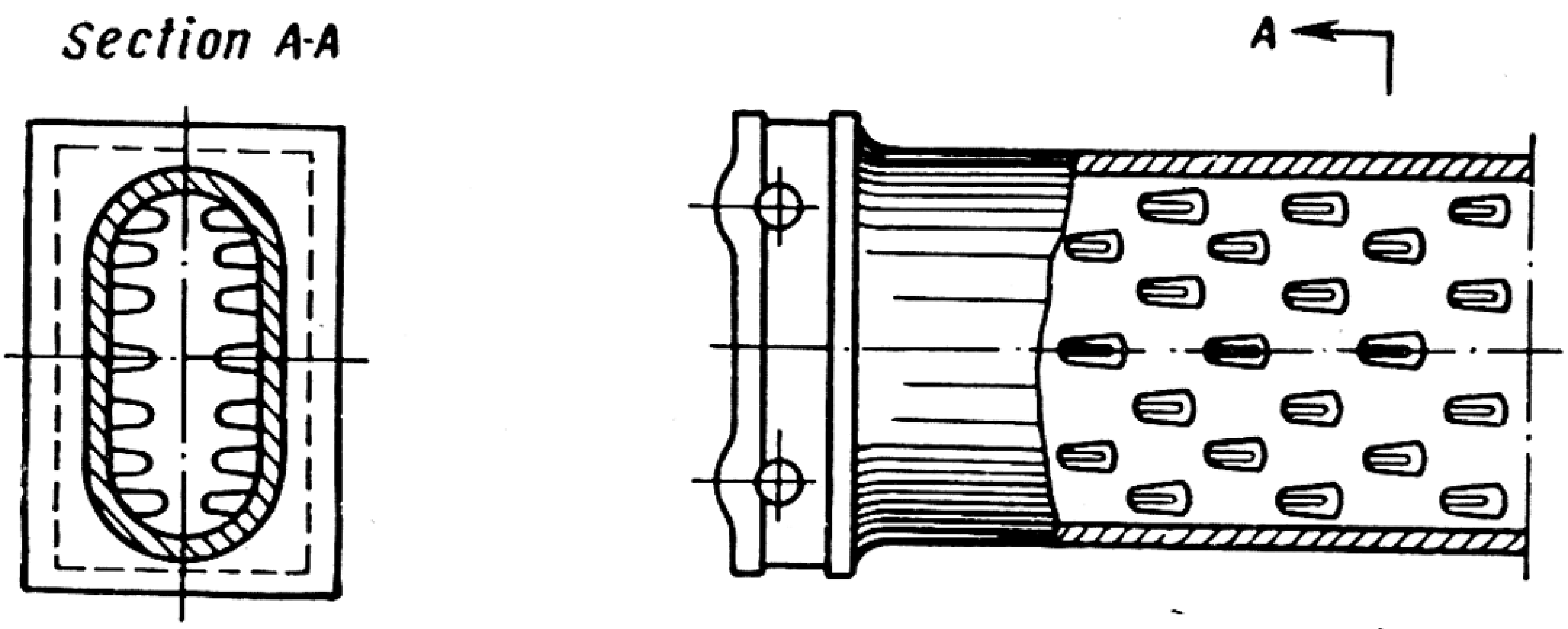


Fig. 48. Needle-type recuperator pipe with internal needles

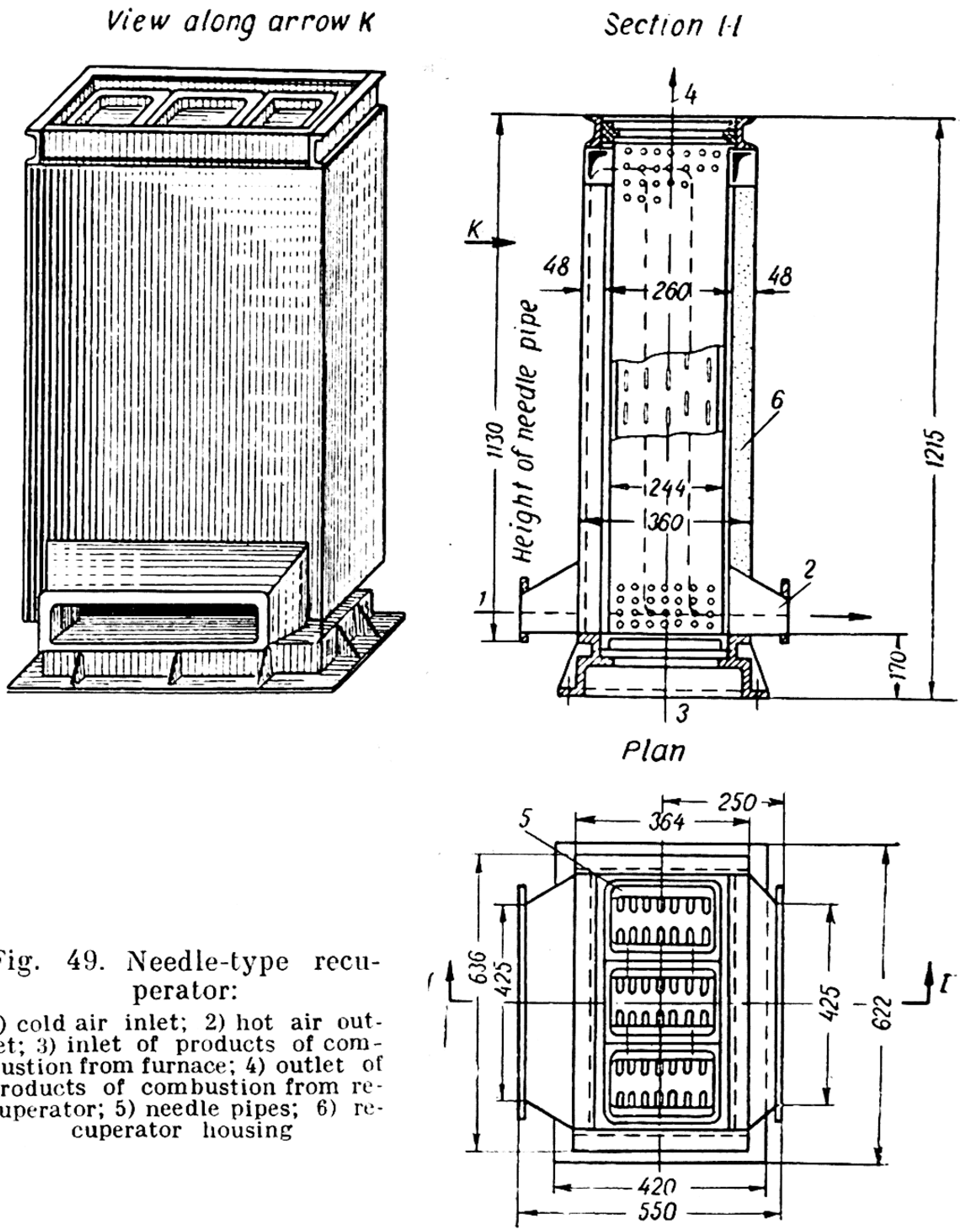


Fig. 49. Needle-type recuperator:

1) cold air inlet; 2) hot air outlet; 3) inlet of products of combustion from furnace; 4) outlet of products of combustion from recuperator; 5) needle pipes; 6) recuperator housing

a long life. But they have one great disadvantage—their high permeability. Air, penetrating the brickwork joints of these recuperators, dilutes the flue gases.

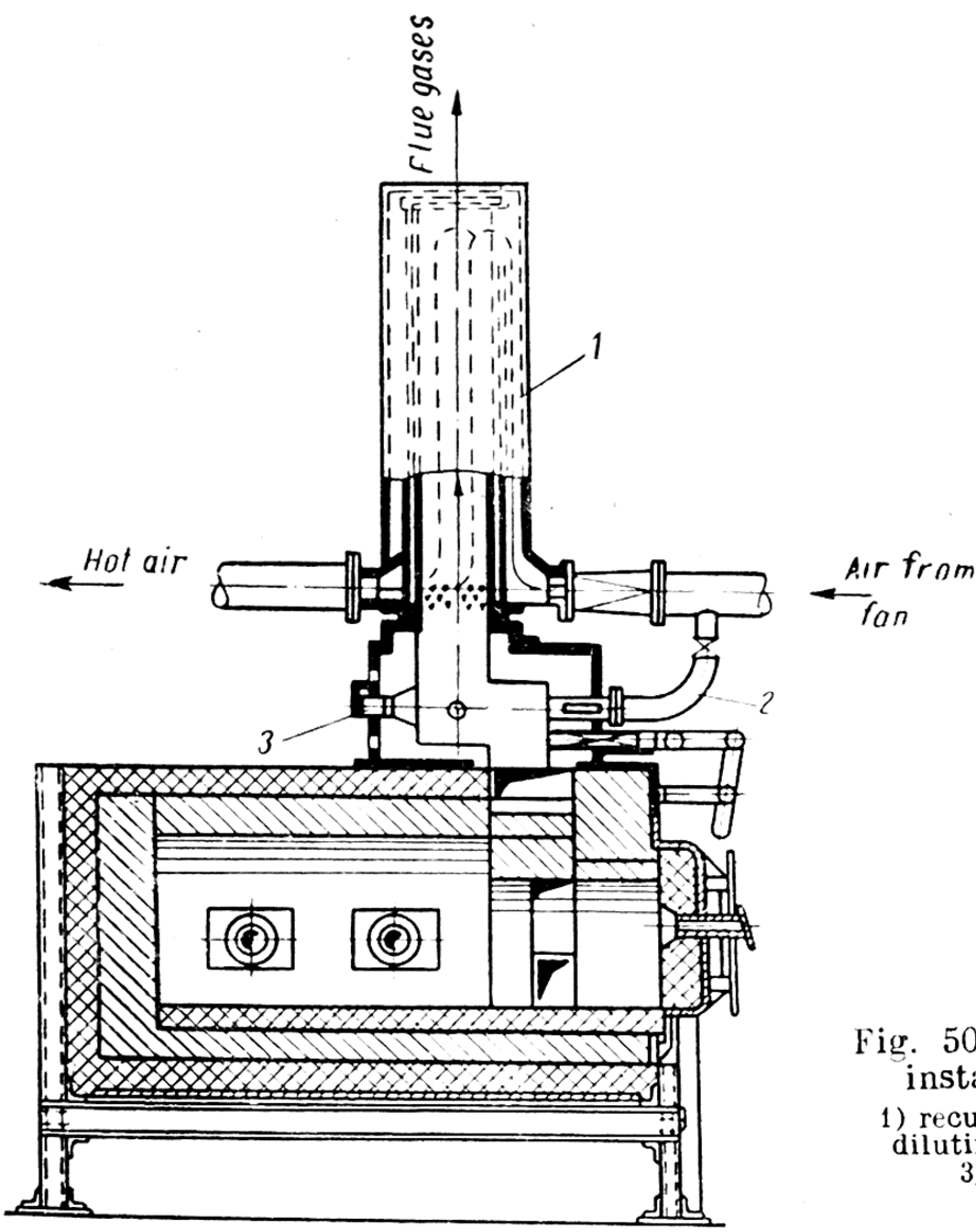


Fig. 50. Small recuperator installed on furnace:
1) recuperator; 2) air line for diluting flue gases with air; 3) inspection hole

The most common type of metallic recuperators are tubular ones, made of cast and seamless drawn needle pipes. Fig. 48 shows the tube of a *needle-type recuperator* with internal needles. Needle-type recuperators are also built with tubes having needles located on both their internal and external surfaces. The needles increase the heating area of the tubes, thus ensuring a better transfer of the heat of the hot gases to the air being heated. Needle-type recuperators are assembled from separate tubes.

In forge shops, recuperators are installed above the furnace, when the products of combustion are discharged upwards from the furnace, or, if they are discharged from the furnace into the flues, inside the latter. Fig. 49 shows a typical small needle-type recuperator,

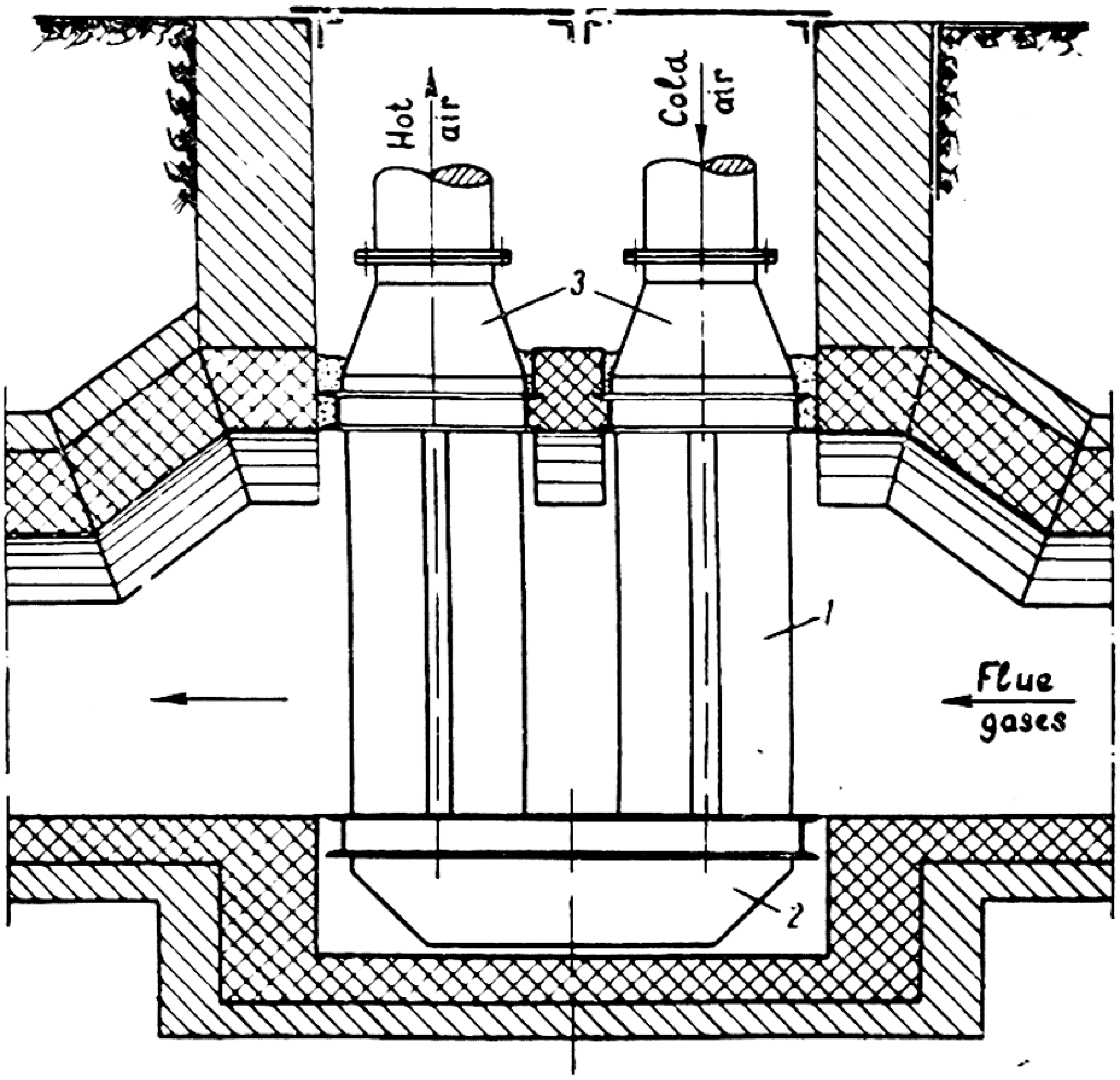


Fig. 51. Needle-type recuperator installed in flue:
1) needle pipes; 2) air header; 3) air inlets

while Fig. 50 shows a similar recuperator installed over a portable gas-fired forge furnace. Fig. 51 shows a needle-type recuperator installed inside a flue.

DISCHARGING PRODUCTS OF COMBUSTION FROM THE FURNACE

As is now known, the hot gases generated during the combustion of the fuel enter the working chamber of the furnace. Here they give up their heat to the metal, thereby raising it to the required temperature. After giving up their heat to the metal, these gases must be removed from the furnace and replaced by new gases at high temperature from the combustion chamber or the burners.

Smoke flue gases are discharged from furnaces: 1) through *flues* into the *chimney*; 2) through special channels laid in the walls of the furnace, and through the charging doors under the hood, whence they are discharged beyond the shop area along pipes. The most common and most sanitary method of removing the products of combustion from a forge furnace is by discharging them downwards, i. e., through flues into the chimneys. How are the products of com-

bustion forced into the flue and thence into the chimney, i. e., how are they made first to descend and then ascend?

It is well known that light substances always tend to rise, i. e., to displace heavier substances. For instance, a piece of wood, immersed in water, will float to the surface because it is lighter than water. The same thing takes place inside a furnace. Gases, like all matter, expand on heating. Let us, for instance, take a cubic metre of gas at a temperature of 0°C. It will weigh 1.2 kg. If we heat it to 820°C, its volume will expand fourfold, i. e., the weight of 1 cubic metre of hot gas will not be 1.2 kg, but $\frac{1.2}{4}$ kg$=$0.3 kg, i. e., one quarter of the weight of 1 cubic metre of cold gas. The operation of the chimney is based on the difference in the weight of the hot gas and of the cold air surrounding the furnace.

Fig. 44 gives a schematic section of a furnace with flues and a chimney. The combustion chamber is subject to the pressure, from above, of a column of air equal to the height of the chimney and, from below, of a column of hot gas, likewise equal in height to that of the chimney. Since the weight of the column of hot gas is less than that of a similar column of cold air, the upper column of cold air tends to displace the hot gases inside the furnace. The greater the temperature at the top of the chimney, the greater will be the difference between the weight of the columns of cold air and gas, and the greater will be the *draught*. Moreover, the greater the height of the chimney, the greater will be the difference between the pressure of the columns of air and gas and the greater the draught.

When starting up newly built furnaces, or furnaces which have been standing idle for long periods, it often happens that the gases, instead of escaping through the chimney, escape from the furnace through the slots into the shop. To ensure the discharge of the gases straight through the chimney, a fire must be lit at the chimney base; this, heating the chimney and the air inside it, creates a draught, and the gases flow up the chimney.

Careful use should always be made of the chimney draught. As a rule, the flue of each furnace is fitted with a damper (valve) for regulating the draught. The furnace should always be so regulated with the valves or damper, that the pressure on the furnace hearth is always equal to that of the surrounding air; cold air will then never be drawn into the furnace, and hot gases will never leak from it. This, however, is very difficult to accomplish in practice. To ensure the proper operation of a furnace, the pressure inside it should be maintained slightly above that of the atmosphere, i. e., above the pressure of the air surrounding the furnace. Then the flue gases will escape only in slight quantities from the dampers, slots, etc., while cold air will not be drawn into the furnace, and the heat losses entailed

in heating extra cold air will be reduced to a minimum. The most important result, however, will be that losses due to oxidation and scale of the steel being heated in the furnace will also be reduced to a minimum.

TYPES OF FORGE FURNACES

Forging shops process a great variety of work, both as regards weight and shape; for this reason, there are very many different designs of forge furnaces.

1) *As regards heating*, furnaces are classified into box-type, semi-continuous and continuous furnaces. In box-type furnaces the temperature is the same in the entire working chamber, but in continuous furnaces it varies, rising from the beginning of the working chamber to a higher temperature at the exit. The steel, charged into the furnace from one end, travels slowly along the hearth from the low-temperature zone to the high-temperature zone, against the direction of the gas flow, and is discharged from the opposite end of the furnace at the required high temperature. In these furnaces steel is heated gradually and continuously, whence their name—continuous furnaces.

Semi-continuous furnaces are, in effect, identical with ordinary continuous furnaces, only they are built with a shorter low-temperature preheating zone; steel can be heated more rapidly in these furnaces than in ordinary continuous furnaces.

2) *As regards charging and discharging methods*, furnaces are further classified into continuous and periodically operated furnaces, so called batch-type furnaces. In furnaces of latter type, the steel is charged through the charging door on to the furnace hearth, where it remains without being moved during the entire heating period; and, as a rule, it is discharged from the furnace through the charging door. An example of a batch-type furnace is the box-type furnace.

In *continuously operated* furnaces, the steel travels along the furnace hearth during the entire heating cycle. In these furnaces the steel can be made to travel by various means. If rectangular ingots or stock are being heated in a continuous-type furnace, they are moved along the furnace hearth with the aid of a pusher. Round stock, however, will be heated in a furnace built with an inclined hearth, along which the stock can be rolled. Such furnaces are called roller-hearth furnaces.

In addition to the above-mentioned continuous-type furnaces, the following types of furnaces are also employed: rotatory, plate, conveyor furnaces, etc. All these belong to the group of mechanised furnaces.

3) *Depending on the type of fuel* burnt in the furnaces, they are classified as: coal-fired, gas-fired, masout-fired and pulverised-fuel fired furnaces.

4) *As regards heat sources*, furnaces can be classified as flame and electric furnaces. In flame furnaces, the heat is generated by the combustion of fuel, whereas in electric furnaces, the heat is generated by electric power.

5) *As regards the method of utilising the heat* escaping together with the products of combustion, forging heating furnaces are classified as recuperator- or regenerator-type furnaces.

BOX-TYPE FURNACES

Box-type furnaces are widely employed in forging shops for heating small and medium size stock. There is a great variety of designs of box-type furnaces, each differing in the location of their charging doors, their firing devices and the methods employed for discharging the products of combustion.

A distinction is also drawn between *stationary* and *portable* box-type furnaces. In stationary box-type furnaces the products of combustion are usually directed downwards, i. e., into a flue, and thence into the chimney. In portable box-type furnaces they are discharged upwards, under a hood, from which they flow along a pipe above the roof of the shop.

Portable furnaces are usually small in size. They are very convenient as, in case of repairs, they can be removed by means of an overhead crane, and replaced by a reserve furnace; this reduces idle time of equipment to a minimum. Moreover, inasmuch as they need no special foundations or flues, they are cheaper to build than stationary furnaces.

Figs. 52 and 53 show a small *portable box-type furnace* designed for operating on either gas or liquid fuel. The fuel is burnt in a burner or an atomiser in chamber *1*. The products of combustion are directed into working chamber *2*, where they are completely burnt; from the working chamber they are discharged through channel *3* under the hood (not shown in the drawing). The metal is charged and discharged through charging door *4*.

Fig. 54 shows a small coal-fired box-type furnace. The fire-box, which is of the semi-gas type, is equipped with a horizontal grate *9* with shaking fire-bars. The fuel is loaded into the furnace through stoke hole *7*, which can be closed by a door. The air required for the combustion of the coal is delivered to the ashpit along pipe *10*. The process of combustion, however, is not limited to the fire-box. As the gases rise and pass through the outlet into the working chamber of the furnace, they meet a stream of auxiliary (secondary) air.

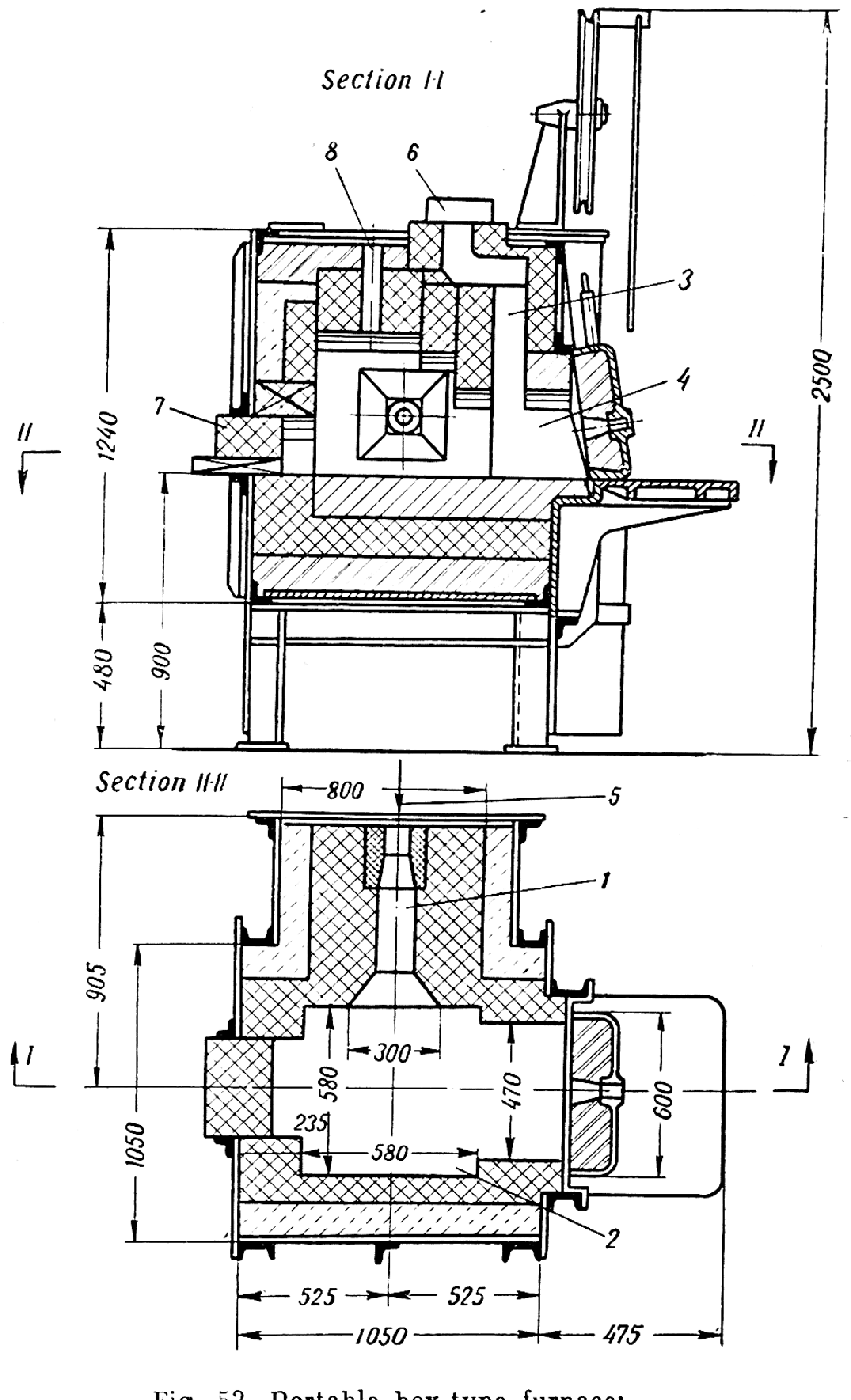


Fig. 52. Portable box-type furnace:

1) masout or gas combustion chamber; 2) working chamber; 3) ducts for removing products of combustion; 4) charging opening; 5) burner or atomiser; 6) bricks for regulating draught; 7 false door (can be broken out for heating central parts of long stock); 8) thermocouple installation pocket

This secondary air is delivered at a high speed through a series of small ducts *5*. As the completion of the combustion of the gas takes place in the working chamber of the furnace, i. e., above the surface of the metal being heated, the temperature inside the working chamber rises and, with it, the productivity of the furnace. From the furnace, the gases flow through ducts in the furnace hearth into the flues and thence—into the chimney. Small furnaces have only one charging opening *4*; furnaces of medium size—two, one for charging and one for removing the stock.

Fig. 55 shows a box-type *gas-fired* furnace with two charging openings. The gas is burnt through two burners

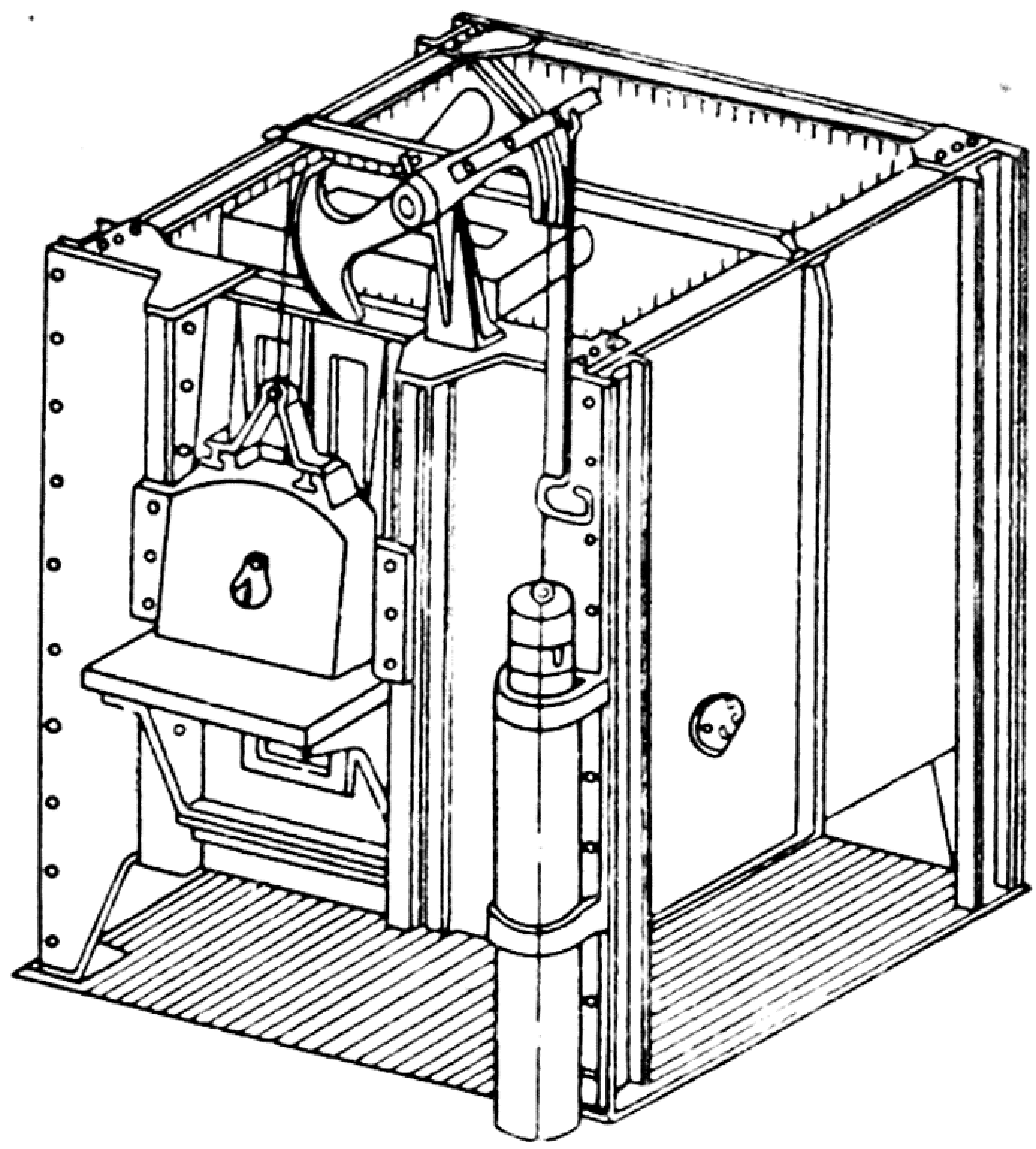


Fig. 53. Exterior view of portable box-type furnace

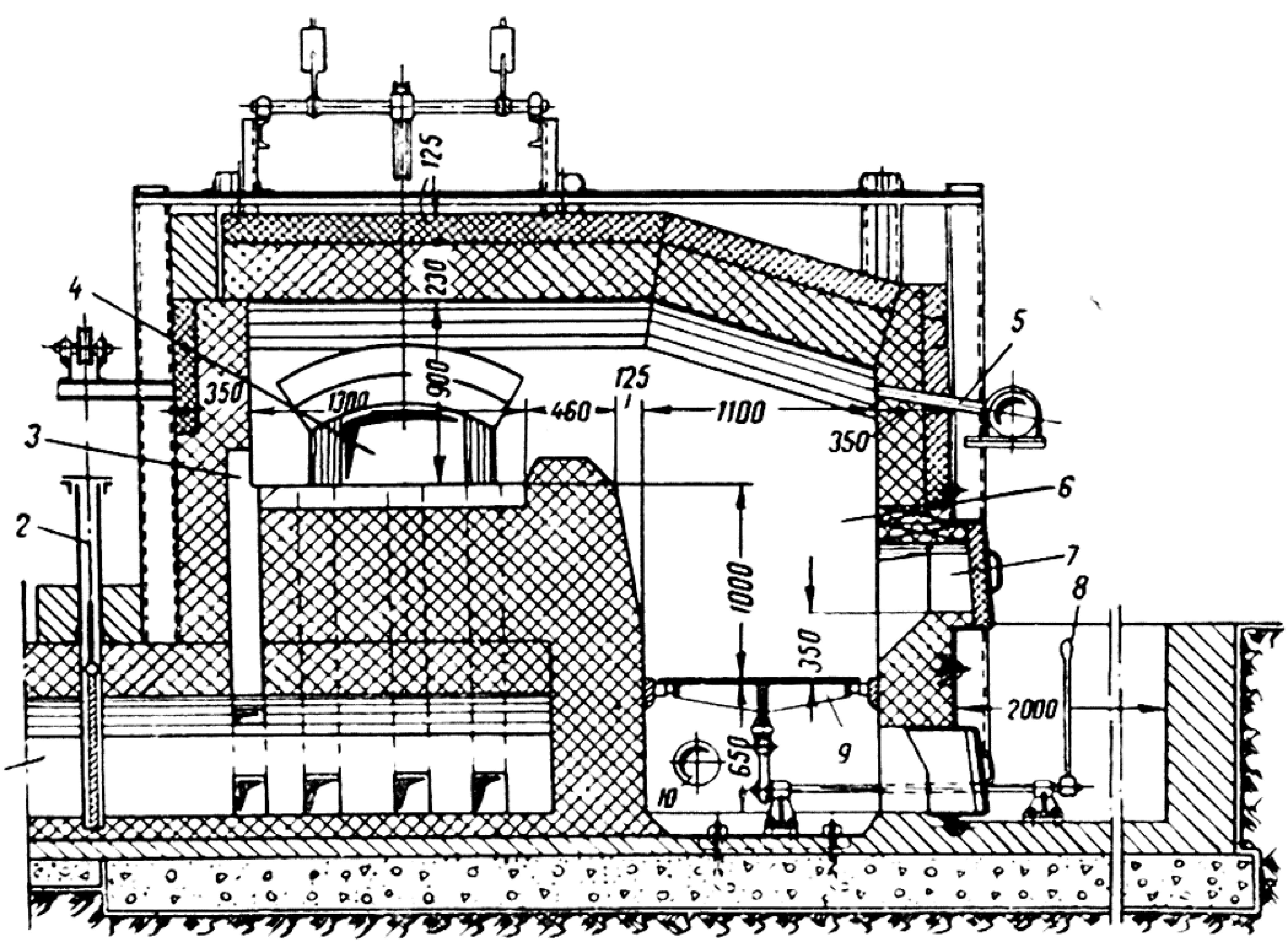


Fig. 54. Coal-fired box-type furnace

1) flue; 2) damper; 3) duct for discharging gases into flue; 4) charging opening; 5) secondary air supply; 6) firing chamber; 7) stoke hole; 8) arrangement for shaking fire-bars; 9) grate; 10) air delivery

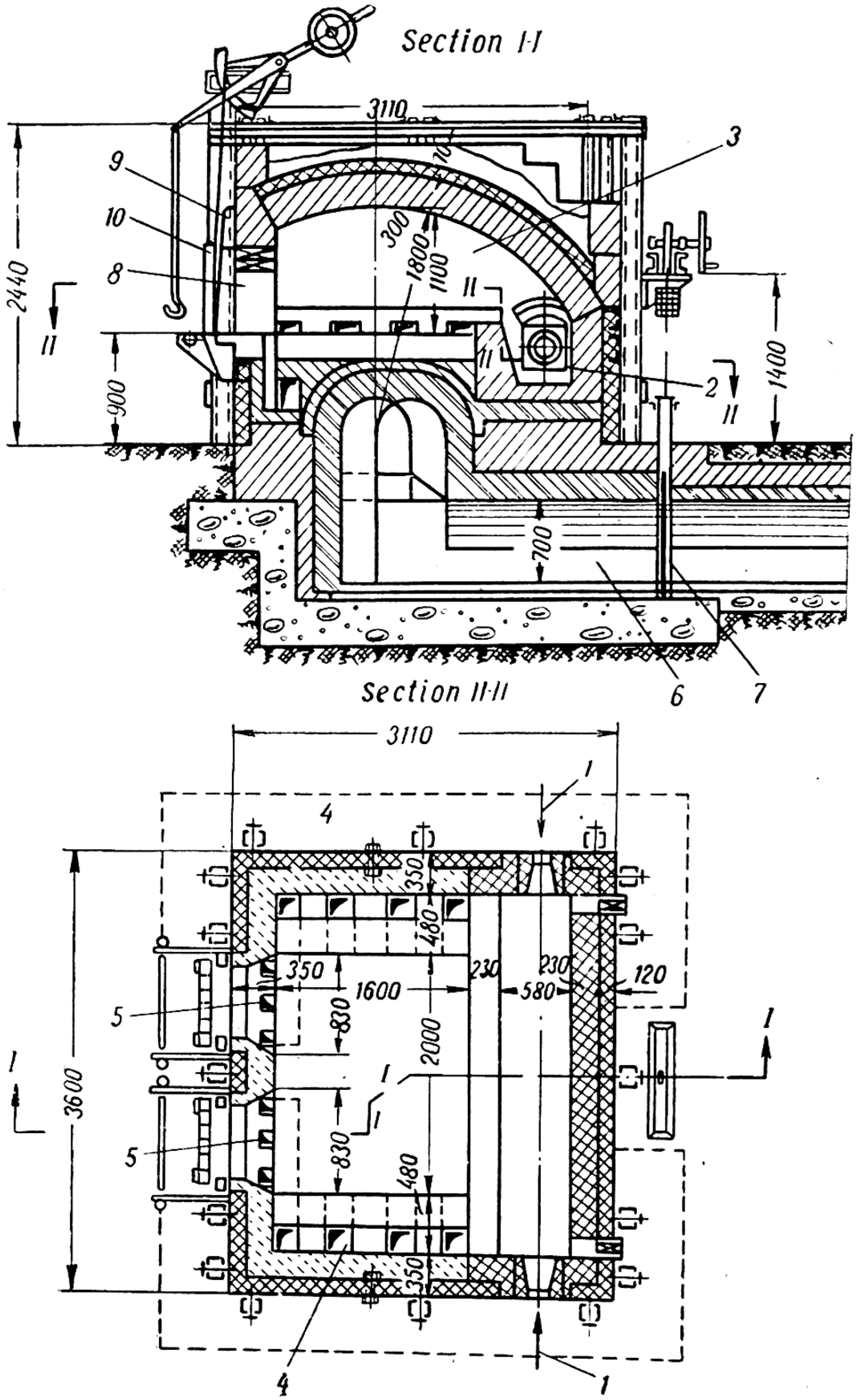


Fig. 55. Box-type furnace with two charging openings

1 in combustion chamber *2*, after which it flows into working chamber *3*, and then along ducts *4* and *5*, which are located symmetrically along the furnace hearth; from these ducts the gaseous products of combustion are discharged into flue *6* and then into the chimney. Flue *6* is equipped with damper *7* for regulating the draught, i. e., the pressure of the gases in the working chamber.

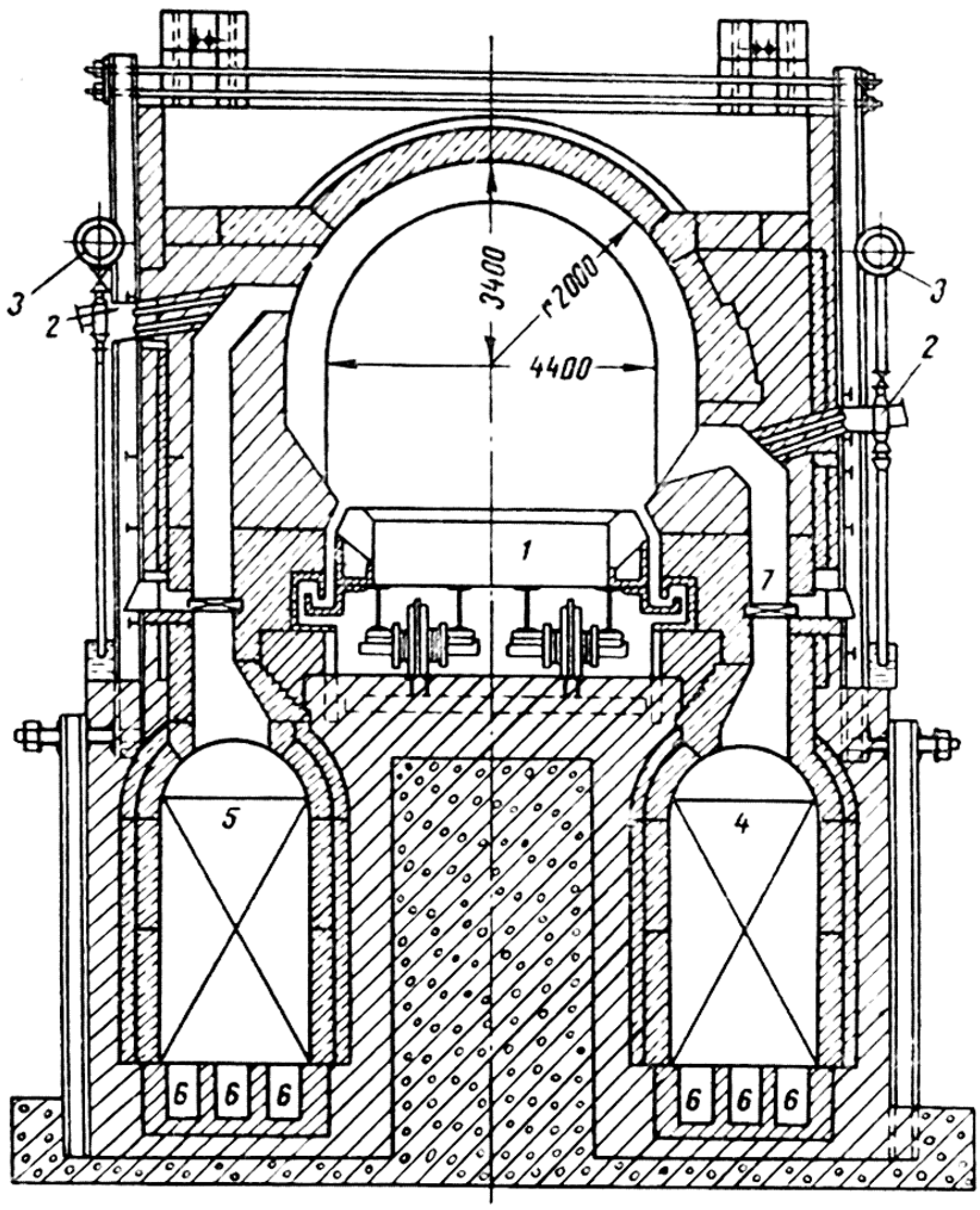


Fig. 56. Regenerator-type furnace for heating heavy ingots

The cold stock is loaded into the furnace, and, after being heated to the required temperature, is withdrawn from the furnace through charging openings *8*. These charging openings are equipped with water-cooled sliding frames *9* and water-cooled sliding doors *10*, to improve working conditions in the vicinity of the furnace.

Box-type furnaces are also employed for heating large heavy ingots for forging in forging presses or high-power hammers. Such furnaces are built with sliding hearths. Fig. 56 shows a gas-fired box-type furnace designed for heating large-size ingots. A heavy car *1*, of welded construction, lined with firebrick, serves as a hearth. This car bottom hearth is rolled in and out of the furnace mechanically.

Box-type furnaces are usually fired with gas or liquid fuel. Their design depends on the character of production. When built for heating small ingots for forging, the hearth (car bottom) of the furnace is designed for heating several ingots simultaneously; large ingots are heated in furnaces designed to take only one ingot, the furnace temperature being raised gradually to ensure the ingot being heated uniformly throughout its entire section, and to avoid the occurrence of cracks in the ingot.

Burners *2* are located in staggered order in the side walls of the furnace; the gas is supplied to the burners through pipe *3*; the burners operate alternately: first—those on one side, and then those on the opposite side. Two regenerators *4* and *5* are located under the furnace for heating the air. They operate as follows: while the row of burners in the left-hand wall is operating (those in the right-hand wall being shut off), the products of combustion flow into the right-hand regenerator *4*, where they give up their heat to its checker-work and flow out through ducts *6* into the chimney. At the same time, cold air flows into left-hand regenerator *5*, where after being heated by the hot checker-work, it flows into the burners through duct *7*.

After the checker-work of the left-hand regenerator has cooled down (i. e., after it has transferred its heat to the incoming air), the burners are switched over: those in the left-hand wall are switched off, and those in the right-hand wall switched on. The products of combustion will then flow from the furnace into left-hand regenerator *5*, heating up its checker-work, while cold air will be delivered into the right-hand regenerator where, after being heated by the brickwork of the latter, it will flow along channels *7* to the burners. The burners are switched over every 30-40 minutes.

MECHANISED FURNACES

Mechanised furnaces are employed for heating large quantities of small and medium size stock. There are many designs of mechanised furnaces, such as: rotatory, plate, conveyor and other types.

Continuous, semi-continuous and rotary-type furnaces are widely employed in forging practice. Continuous furnaces are employed for heating stock which can be easily pushed along the furnace hearth, i. e., for heating square or rectangular shaped sections. Rotary-type furnaces are employed for heating stock whose shape makes it difficult for them to be pushed along the hearth (such as small lengths, flat circular stock) and also for heating stock of round section.

Fig. 57 shows a *continuous-type furnace*, the working chamber of which comprises a continuous heating and soaking section. The cold stock is charged through opening *6* at one end of the furnace, and is

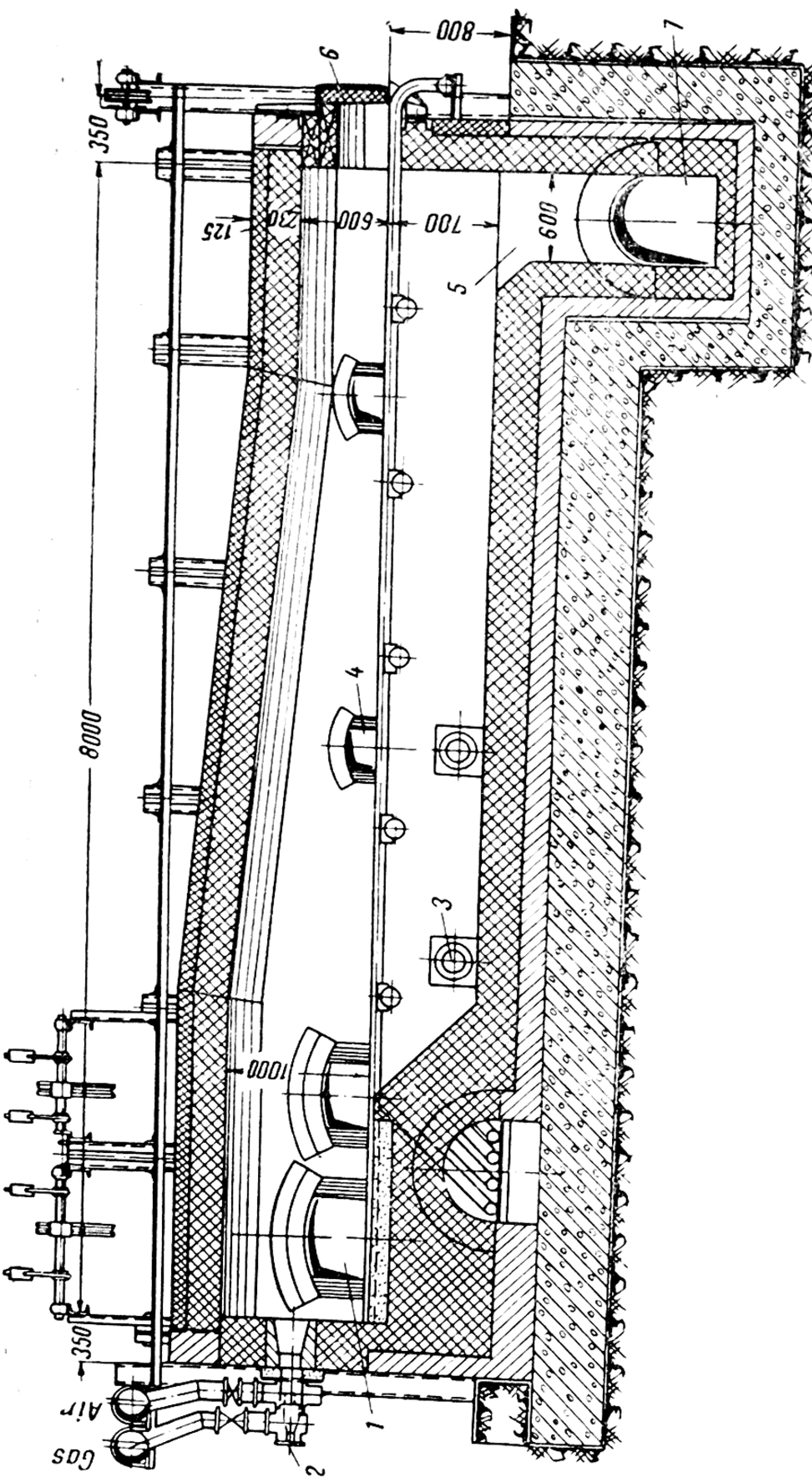


Fig. 57. Continuous-type heating furnace

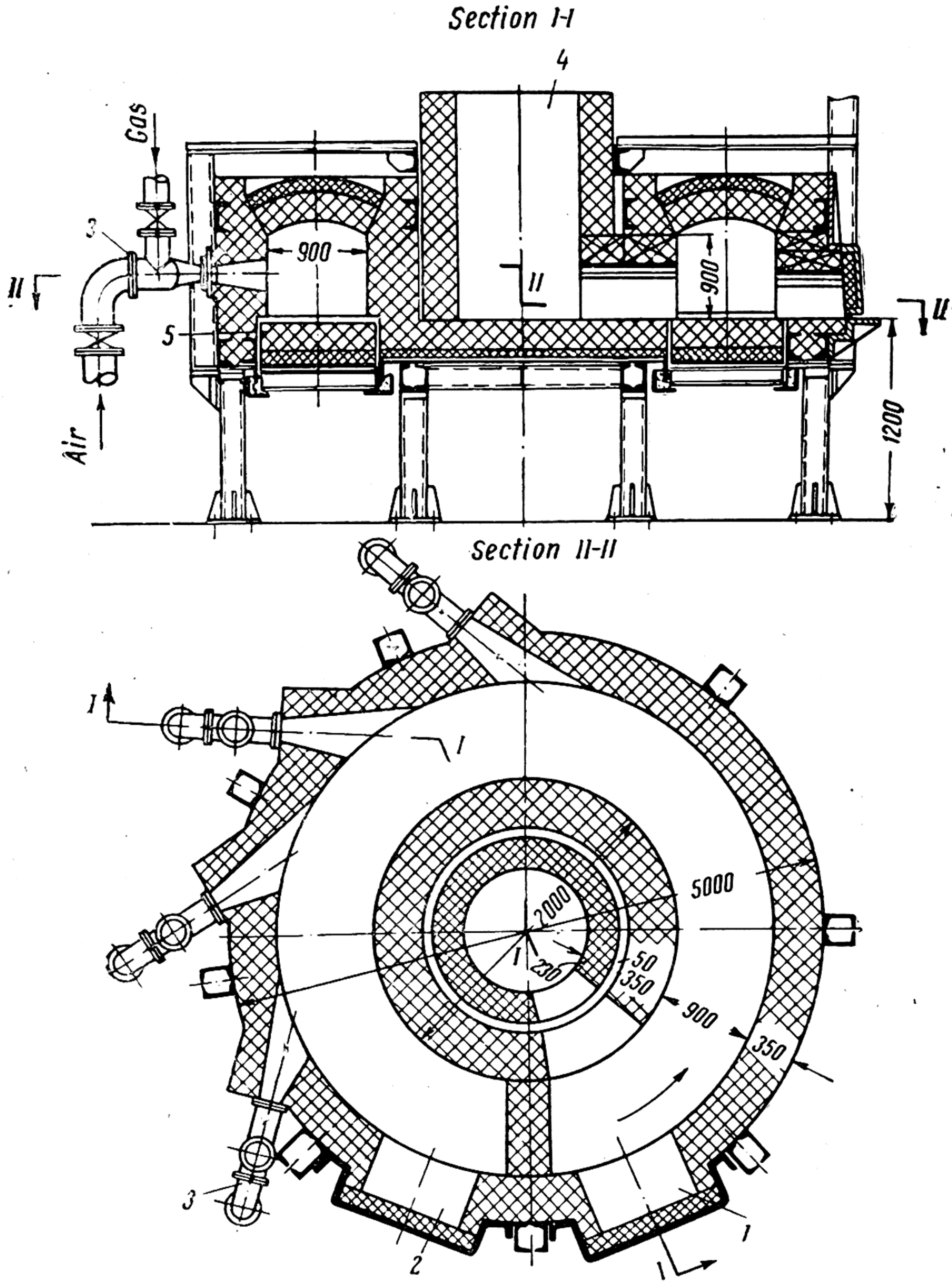


Fig. 58. Rotary-type heating furnage

delivered by a pushing device into the heating and thence into the soaking section of the furnace. As it travels along the working chamber, it is subjected to an increasing temperature. The gradual heating ensures a more uniform temperature through its entire section.

The heated stock is discharged through opening *1*. Along the entire length of the side walls of the furnace handling openings *4* are located, through which the ingots can be turned over with the aid of a bar, thus ensuring their more uniform heating. The atomisers *2* of masout-fired furnaces, or the burners *3* of gas-fired furnaces are installed in the ends of the furnace. In some designs of continuous furnace the burners or atomisers are installed along the entire length of the side walls. The products of combustion are discharged along ducts *5* into flue *7* and thence into the chimney.

Continuous furnaces can also operate on solid fuel, in which case they are equipped with a fire-box for burning the solid fuel. From the fire-box the hot gases flow into the working chamber of the furnace, where they heat the metal to the required temperature.

Fig. 58 illustrates a *rotary-type furnace* with a circular hearth. Cold stock is charged into the furnace through charging opening *1*; the hot stock is discharged from opening *2*. The furnace is heated with burners or atomisers *3*, located near the discharging opening. The products of combustion flow to meet the metal being heated and are discharged into smoke duct *4*. The speed of the rotating hearth is calculated for heating the stock to the required temperature in one revolution. Hearth *5* of the furnace is rotated with the aid of special mechanisms.

MUFFLE-TYPE FURNACES

In muffle-type furnaces the hot gases do not come into contact with the stock or forgings being heated. Fig. 59 shows the schematic section of such a furnace. The stock is placed inside a muffle, which consists of a box, open from the side adjacent to the charging opening. The muffle can be made of cast iron, heat-resistant steel or any refractory material. It is placed inside the furnace, where it is washed on all sides by hot gases. The heated walls of the muffle radiate heat and raise the temperature of the work inside the muffle. As the work does not come into direct contact with the hot gases, it will be heated without forming any scale,. i. e., with a clean surface.

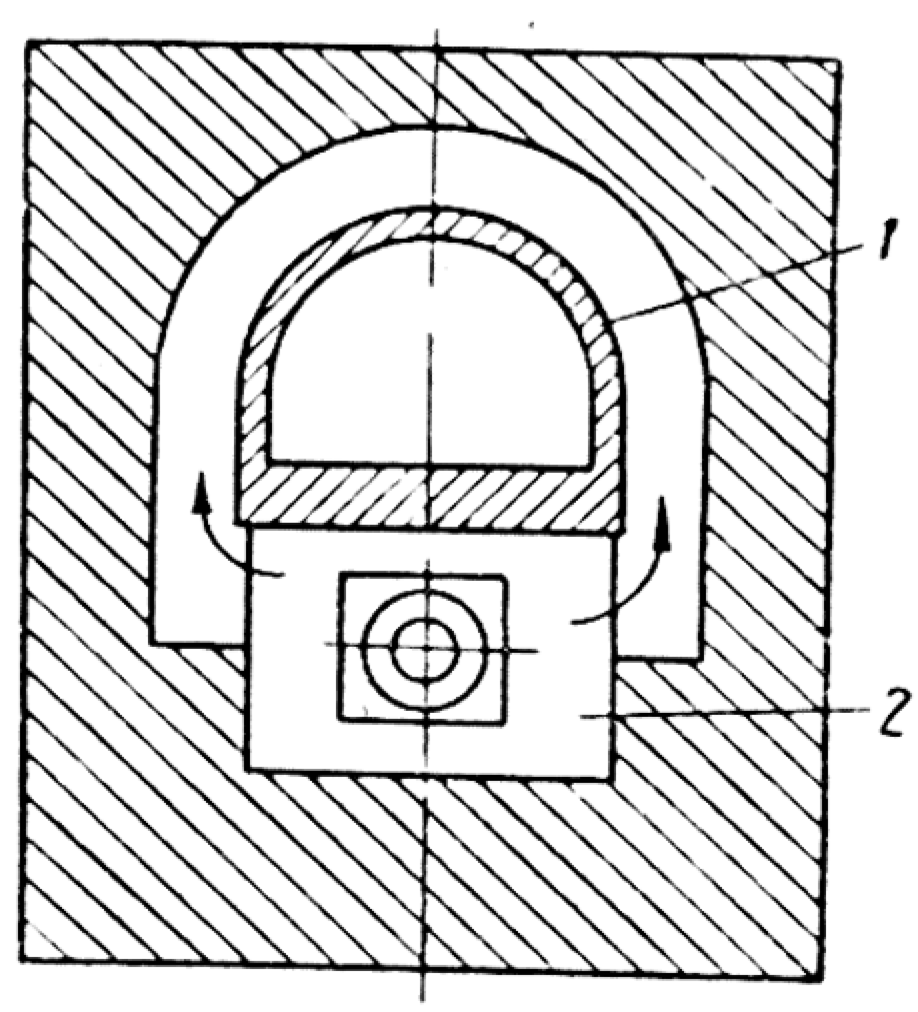


Fig. 59. Scheme of a muffle furnace:
1) muffle; 2) fire-box

Muffle-type furnaces are mainly employed for heating nonferrous metals or steel forgings whose dimensions must be maintained precisely and whose surface must be kept clean of scale.

FURNACE BUILDING MATERIALS

The following building materials are mainly used for building forge heating furnaces: refractory brick, insulation material, red brick, concrete and building mortar.

Building materials employed for heating devices are called *refractories*. Refractories possess the property of resisting the action of high temperatures, as well as those physical and chemico-physical processes (for instance, corrosion by slags) which take place in furnaces at high temperatures. Fire-clay (grog), dinas, and talc brick are the main refractories employed, while fire-clay is used for mortar in forge furnaces.

Fire-Clay (Grog) Brick. Fire-clay brick is the chief material used in building furnaces.

Properly prepared and baked fire-clay brick is an excellent refractory material. Its chief quality is its resistance to sudden fluctuations in temperature. Furnaces built of fire-clay brick can withstand repeated short shut-downs, be completely cooled and then rapidly heated to a temperature of 1,150-1,300°C in a few hours, without any harmful effect on the masonry.

Grog (fire-clay) is a neutral material and is but slowly attacked by ferrous slags. The disadvantage of fire-clay brick is that, in spite of its high refractoriness (its melting point is up to 1,750°C), it commences to deform at 1,250-1,400°C. For this reason fire-clay brick is usually used for lining furnaces designed for a maximum temperature of 1,350°C.

Depending on its refractoriness, ordinary fire-clay brick is classed as A, B and C fire-clay brick. Class A and B fire-clay bricks, depending on their surfaces and textures, and the accuracy of their dimensions, are further sub-classified into three grades (grades 1, 2 and 3) and Class C fire-clay brick into two grades (grades 1 and 2). Class A fire-clay brick is used for building or lining furnace parts which are subject to temperatures up to 1,300°C; Class B fire-clay bricks may be used for making furnace parts designed for a maximum temperature of 1,250°C; while Class C fire-clay bricks may be used for parts designed for a maximum temperature of 1,200°C. In forge furnaces, Class A fire-clay bricks are used for building fire-boxes and roofs; the walls are built of Class B fire clay brick.

Dinas Brick. Dinas brick has greater refractoriness than fire-clay

brick. It is made practically entirely from ground quartz and for this reason is often called quartz brick.

Dinas brick possesses a very high refractoriness (1,650-1,750°C). Its chief disadvantage lies in its weak resistance to sudden temperature changes—it is liable to crack on being rapidly heated or cooled. For this reason, if a furnace or its parts are built of dinas bricks, it must be heated or cooled slowly, particularly between 200-600°C.

Dinas brick is not recommended for building or lining forge furnaces, especially furnaces of periodical operation. In exceptional cases dinas brick may be used for forge furnaces when fire-clay brick cannot withstand the maximum temperatures in the furnace, i. e., in the fire-boxes.

Talc Brick. Talc brick is manufactured from talc shale—a soft mineral of scaly texture, which is smooth to the touch. The bricks are sawn out of natural talc stone and then baked in kilns. The melting point of natural talc is about 1,500°C.

Talc has an excellent resistance to scale and ferrous slags formed in heating furnaces at high temperatures. Talc brick softens at about 1,350-1,400°C; its heat resistance is rather low and for this reason it is employed for furnaces which are not designed for sudden temperature changes. Talc brick is employed for lining forge furnace hearths.

Magnesia Brick. Magnesia brick is manufactured from magnesite, a natural mineral. Magnesia brick possesses a high refractoriness, melting at about 2,000°C; however, it shows signs of deformation under load at 1,500°C. Magnesia brick, on deformation, begins to split, and for this reason cannot be used for such forge furnace parts as roofs and arches.

Magnesia brick is also expensive, and is seldom used for building forge furnaces (only for hearth linings). The main disadvantage of magnesia brick is its poor resistance to sudden changes of temperature, which cause it to crack.

Chrome-Magnesia Brick. Chrome-magnesia brick is manufactured from baked chromite, a mineral ore.

Chromite brick is unable to resist high temperatures, and begins to deform at about 1,300-1,450°C. Magnesite is added to chromite in order to increase its refractory properties, and such bricks are called chrome-magnesia bricks; they are sometimes used for building the walls and fire-boxes of forge furnaces.

To reduce heat losses through the furnace walls, the outside layers of masonry are lined with what are called heat-insulation materials. *Heat-insulation materials* are poor heat conductors. The chief reason for the poor conduction of heat through insulation materials is their porosity. Among the insulation materials employed for

building forge furnaces are: light-weight fire-clay brick, diatomite and red brick.

The thermal conductivity of light-weight fire-clay brick is from 25 to 20 per cent that of ordinary fire-clay brick. Its refractoriness is approximately the same as that of ordinary fire-clay brick. But, notwithstanding its high refractoriness and poor thermal conductivity, it has material disadvantages, the most important of which are: high permeability, poor slag resistance and poor thermal stability. Light-weight fire-clay brick cracks when subject to sudden changes of temperature, and is easily worn when subject to friction. All these properties combined permit light-weight fire-clay brick to be used for building the outside walls of forge furnaces, i. e., for their insulation, and also for lining the inner walls of furnaces, especially those of the continuous operation type.

Diatomite brick is made from practically the same material as dinas brick (it consists of from 95 to 98 per cent of quartz sand). Its high porosity tends to reduce its thermal conductivity as well as its refractoriness and strength. The permissible temperature to which diatomite brick can be heated is 800-850°C.

Diatomite bricks are employed for laying the outside walls of forge furnaces.

Red brick is used in building forge furnaces as a facing material for lowering the cost of the masonry and increasing its building strength. Red brick has a higher thermal conductivity than light-weight fire-clay or diatomite brick; however, refractory materials are better conductors of heat than red brick. The permissible temperature to which red brick can be heated is 600-700°C.

BUILDING FORGE FURNACES

Knowing the characteristics of refractory materials, we can now determine what materials should be used for building different parts of forge furnaces.

The Combustion Chamber. The temperature in the combustion chamber usually reaches 1,350-1,400°C. Hence it must be built of fire-clay bricks of the first class, while its roof may be built of dinas brick. If the combustion chamber is built with a dividing wall, subject to high temperatures from both sides, and to the action of slag, this wall should be built of chrome-magnesia brick.

The Working Chamber. The inner walls of the working chamber of the furnace are subject to temperatures of 1,250-1,300°C, and its roof—to temperatures of 1,350-1,400°C. Frequent shutting-down of the furnace, charging and discharging the metal, results in considerable temperature fluctuations. As a result the

walls and roofs of the furnace are built of first-class fire-clay brick.

If the furnace is designed for operation not entailing sudden temperature fluctuations, the roof may be built of dinas brick.

The Hearth. The hearth of a forge furnace works under special conditions: apart from the considerable temperature fluctuations to which it is subjected, considerable amounts of scale formed during the heating of the steel accumulate on the hearth. At temperatures of approximately 1,300-1,400°C, scale fuses and combines with the refractory lining to form a liquid slag which corrodes the refractory lining of the hearth (particularly if the latter is made of fire-clay brick). Scale does not fuse at temperatures below 1,300-1,400°C, and thus does not corrode the furnace hearth.

In furnaces built with dry ash-disposing gear, it is advisible to make the hearth with talc brick; sometimes, however, the hearth is made of first-class fire-clay brick. If the furnace is designed for liquid slag disposal, especially in the soaking section of continuous-type furnaces, the hearth is made of chrome-magnesia or magnesia brick, or rammed with chromite mortar.

The Flue. The inner walls of flues are built of low-class fire-clay brick while its outside or bearing walls are built of ordinary red brick.

In order to minimise heat losses through the furnace walls and consequently to reduce the fuel consumption and increase the temperature inside the furnace, the outside layers of the furnace brickwork must be built of heat insulating brick. In forge furnaces lightweight fire-clay or dinas brick is used as an insulating material. Sometimes fillings of powdered heat insulating materials, such as slag wool, are used; in these cases, however, the furnace must be encased in a steel shell.

CONTROL AND MEASURING INSTRUMENTS

The operation of forge furnaces must be kept under constant control. Control and measuring instruments are installed on the furnace to control and to ensure subsequent normal operation. Nowadays the automation of furnaces has come into wide use; here, with the help of corresponding instruments, definite preset temperatures, gas and air pressures, etc., are maintained.

Draught Measurement. We already know that, under the influence of draught, the pressure at the base of the chimney is less than that of the atmosphere; it is called rarified, or negative pressure, and indicates the strength of the draught.

Draught is measured by *draught-gauges*; a draught-gauge consists of a bent glass U tube filled with water to a definite level, as shown

in Fig. 60. One end of the tube is connected to the spot in the flue at which the draught is to be measured. The following then takes place. Before the tube has been connected to the flue, the ambient air exerts an equal pressure in each arm of the tube, and the water in these arms will therefore be at the same level. On connecting one arm of the tube to the flue, where the pressure is less than that of the atmosphere, the pressure in this arm will fall and the external pressure of the air will therefore force the water in the tube towards the arm at a lower pressure. Consequently, the water in one arm will fall, and will rise in the other, coming to rest at different levels. The difference between the levels in the arms of the tube will indicate the difference between the pressure in the flue and that of the atmosphere, i. e., the force of the draught. In addition to the draught-gauge just described, there are other draught-gauges of many different designs, such as orifice draught-gauges, etc.

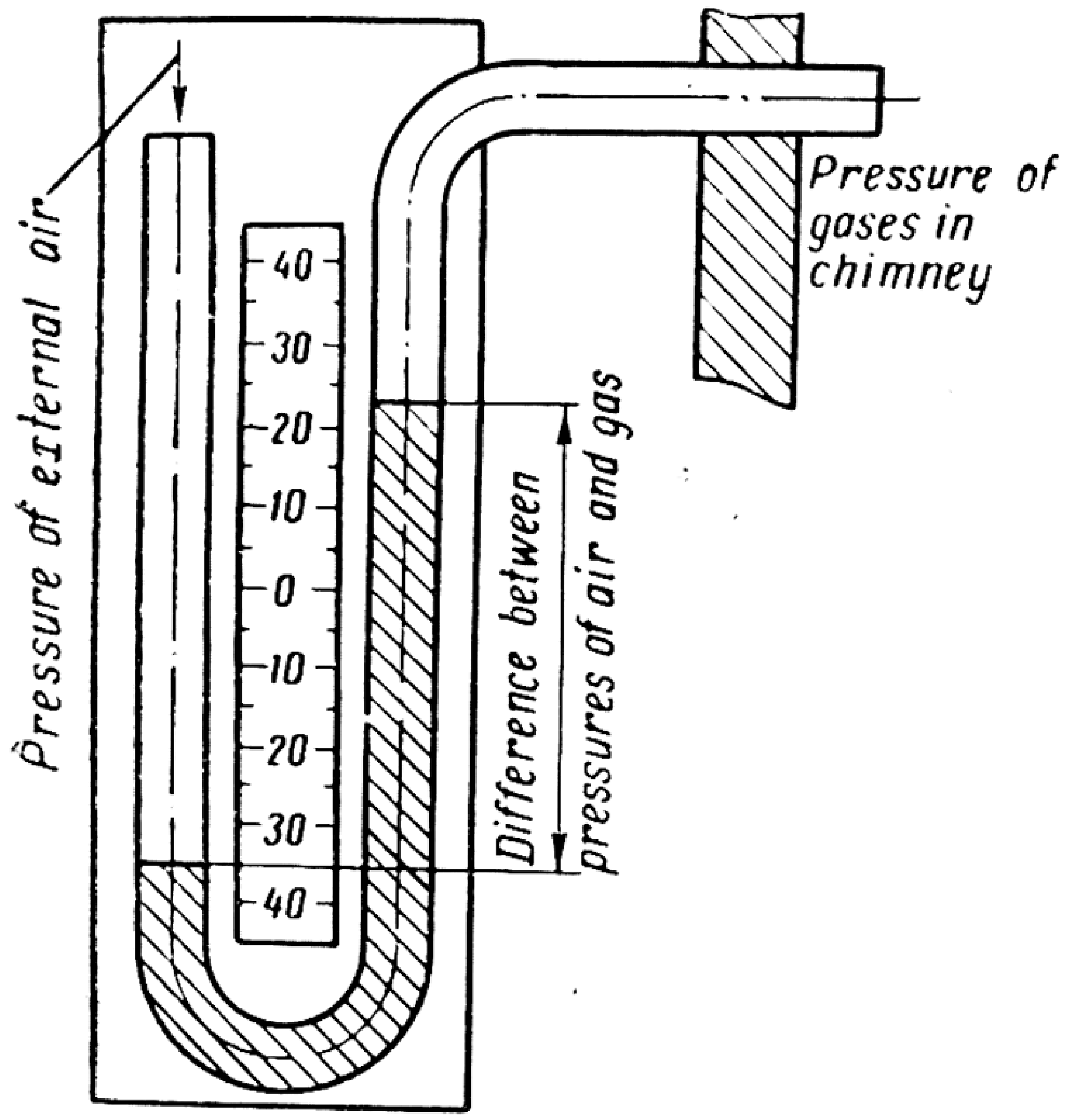


Fig. 60. Scheme of installation of a draught-gauge

Analysis of the Composition of the Products of Combustion. In order to be able to judge whether the fuel is burning properly, the composition of the products of combustion must be known. If the fuel burns completely, the products of its combustion (gases) should not contain any unconsumed matter, i. e., should not contain carbon monoxide, hydrogen, etc. Moreover, the products of combustion should contain no oxygen, as the presence of oxygen is an indication that the fuel is being burnt with a great surplus of air.

Instruments, known as *gas analysers*, are employed for analysing the composition of the gaseous products of combustion. All gas analysers may be divided into two groups: 1) hand instruments, in which the analysis is made by a special person; and 2) automatic gas analysers, which automatically take samples of the gases, analyse them and record the results of the analysis. Manual gas analysers are employed only for observations lasting a short time. Auto-

matic gas analysers are installed on furnaces for the continuous control of the composition of flue gases, and ensure the possibility of determining exactly how the fuel is burning. All faults noted in the operation of the combustion chamber should be immediately eliminated.

For forge furnaces it is necessary to employ instruments capable of indicating the content of carbon dioxide, and that of carbon monoxide plus hydrogen (CO+H).

Measuring the Temperature of the Metal. The temperature of the metal being heated for forging can be determined by two methods: by its temper colour, and by the thermo-electric method.

The temperature of steel can be determined by its temper colour either with the aid of special instruments or by the naked eye. It is obvious that it is impossible to determine exactly the temperature of a metal from its temper colour and, moreover, to do so needs great practice. For this reason, the visual determination of the temperature of a metal from its temper colour is practised only in the process of hand forging, when metals are heated on blacksmith's hearths.

We have previously mentioned the various temper colours of steel and their temperatures. The temperature of hot steel can be more precisely measured from its temper colour with the aid of special instruments, called pyrometers. *Pyrometers*, depending on the principle of their operation, are classified as radiation, thermoelectric (thermocouples) and optical pyrometers. The action of the optical pyrometer is based on the comparison of the temper colour of the heated body with that of the heated filament of an incandescent bulb. Optical pyrometers are employed for measuring temperatures ranging from 700 to 1,800°C.

Fig. 61 illustrates an *optical pyrometer* with a disappearing filament. It consists of tube *1*, measuring instrument (milliameter) *2* and dry cell *3*; the tube is fitted with eyeglass *5* and lens *4*. Photometric incandescent bulb *6* is located inside the tube. The incandescent bulb is connected with rheostat *7*, mounted in the handle of the tube. The latter is connected by a wire to the current source—dry cell *3*, which heats the filament of the incandescent bulb. The scale of the milliameter is graduated in degrees Centigrade.

The temperature of the steel is measured as follows: holding the instrument in his left hand and pointing the tube at the heated object, the observer rotates the ring of the rheostat, thereby changing the current in the incandescent bulb and the temperature of its filament. The rheostat ring is rotated until the colour of the incandescent filament coincides with that of the heated piece of steel whose temperature is being determined.

When measuring temperatures with optical pyrometers, three things may occur, i.e.:

1) The filament of the photometric (incandescent) bulb may appear darker (colder) than the heated body (Fig. 62, *a*). In this case,

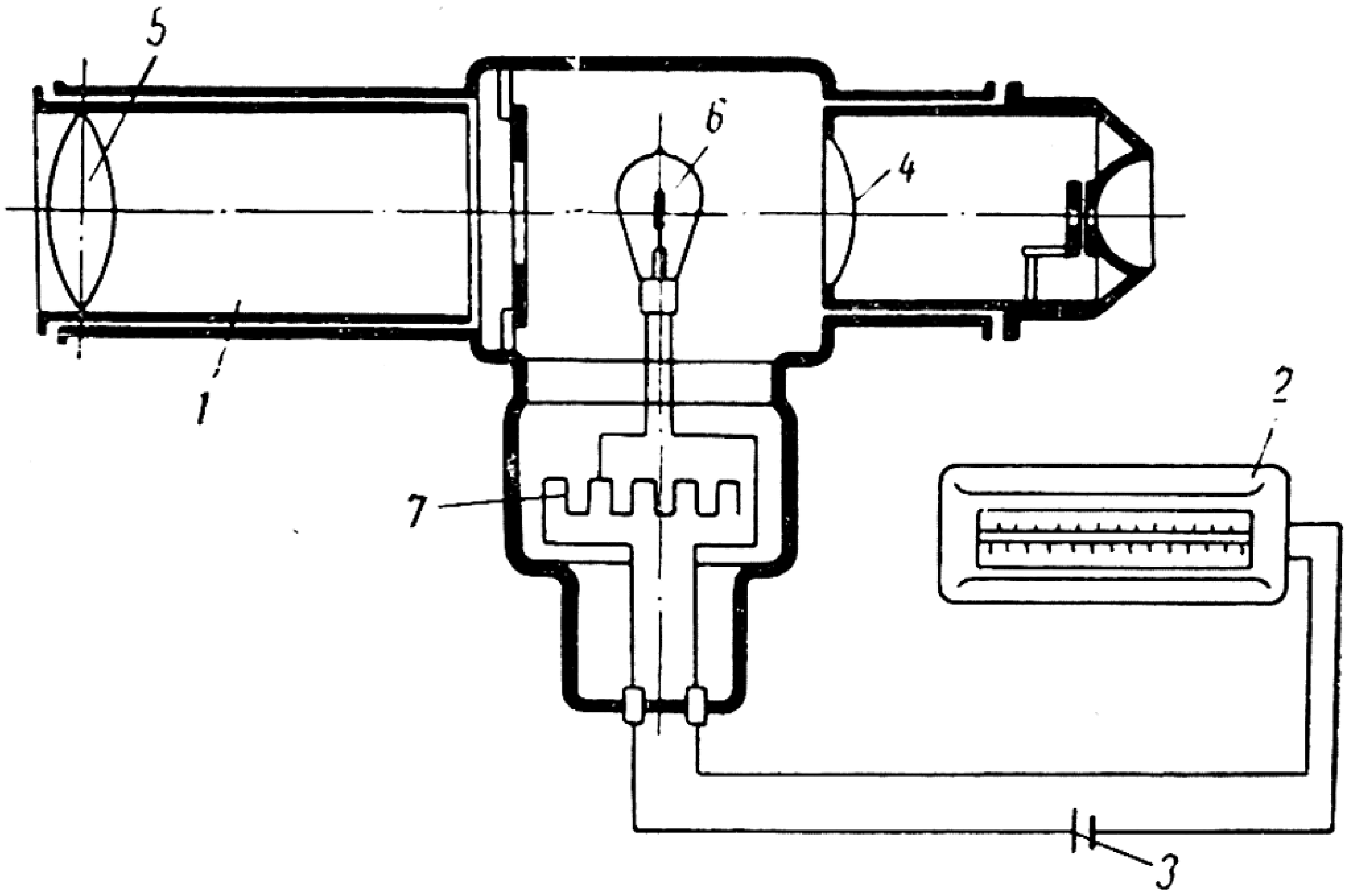


Fig. 61. Scheme of an optical pyrometer

the temperature of the filament is raised by turning the ring of the rheostat;

2) The filament of the photometric bulb may appear to be brighter than the heated body (Fig. 62, *b*). In this case, it is necessary to lower the temperature of the filament in the opposite direction;

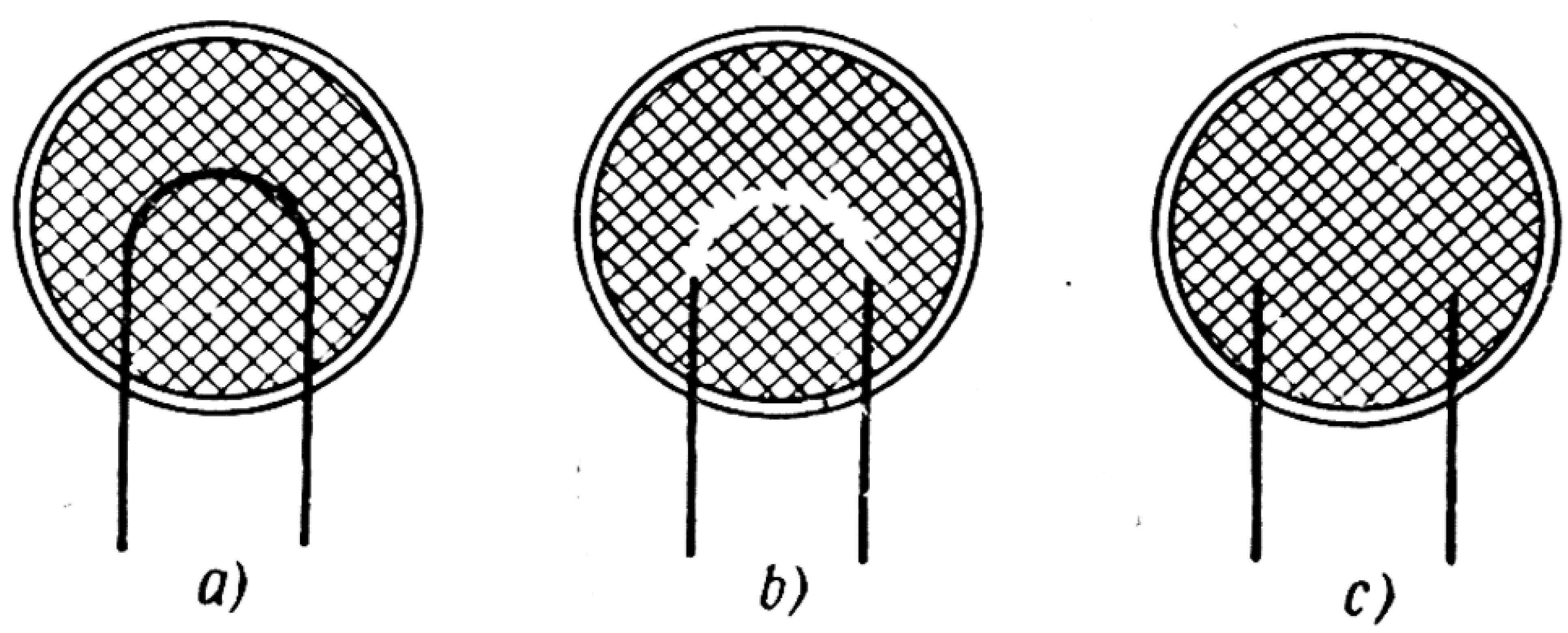


Fig. 62. Three possible cases when measuring temperatures with an optical pyrometer

3) The brightness of the incandescent filament and of the heated body may coincide (Fig. 62, *c*). This indicates that the temperature of the heated body is equal to that of the filament of the incandescent bulb. When this coincidence is attained, the observer reads the temperature of the heated body from the scale.

Optical pyrometers are portable instruments and are employed only for brief temperature measurements. For the constant measuring of furnace temperatures stationary instruments, known as *thermoelectrical pyrometers (thermocouples)*, are employed. They are used for measuring temperatures from 200° to 1,300°C. The operation of a thermocouple is based on the following phenomenon: if we solder two wires of dissimilar metals at one end and apply heat to the junction, an electric current will be generated. The higher the temperature of the heated (hot) junction, the stronger the current will be. The free ends of the joined wires are connected by leads to a

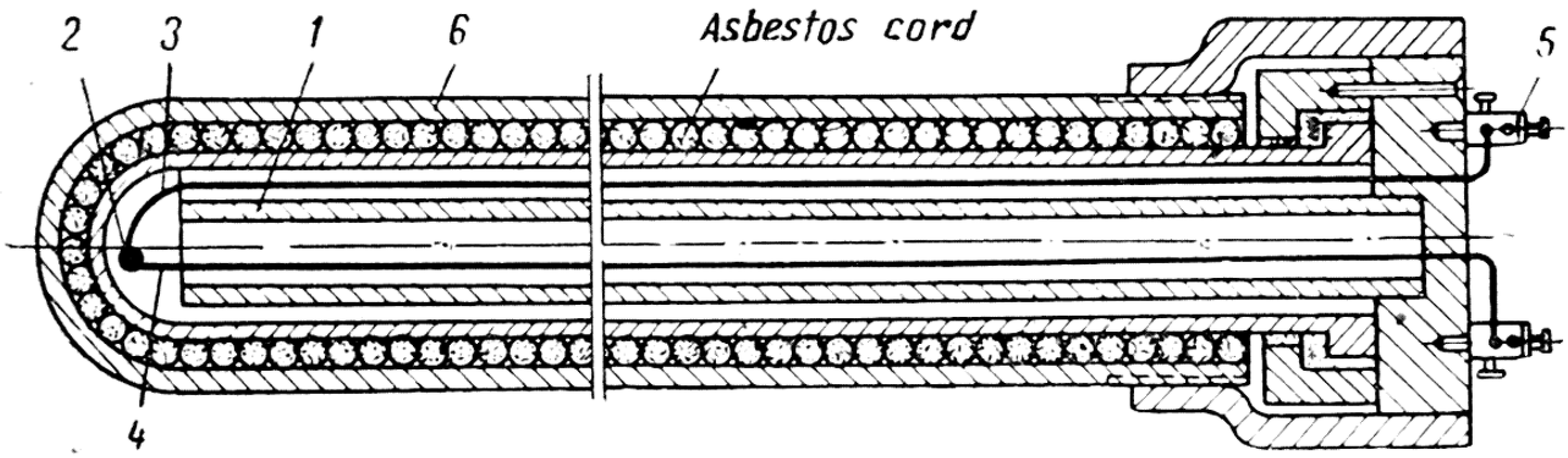


Fig. 63. Thermoelectrical pyrometer (thermocouple)

galvanometer. The electric current generated at the hot junction flows through the connecting wires to the galvanometer, which indicates the measured temperature by the deflection of a needle on its scale. The choice of the metals and alloys used for making thermocouples will depend on the range of temperatures to be measured. The most commonly used thermocouples for the continuous measurement of high temperatures in forge furnaces consist of platinum and platinum-rhodium (an alloy of platinum and rhodium) wires.

Fig. 63 illustrates a platinum platinum-rhodium thermocouple. It consists of a thin-walled porcelain protection tube *1* in which is placed a platinum wire *4*. The second (platinum-rhodium) wire *3* runs along the outside of this tube. The wires are thus prevented from contacting each other along their entire length. The wires are welded together at point *2* (the hot junction). Both wires, together with their hot junction, are enclosed in a second porcelain tube of greater diameter, closed at one end. This second tube is protected by heat-resistant alloy tube *6*. The ends of the wires are led through the head of the tube to terminals *5* and connected to the wires leading to the galvanometer.

Two types of galvanometers are available: indicating and recording. Recording galvanometers, in addition to indicating temperatures at any given time, also record the temperature fluctuations

for definite time periods, thus enabling the operation of the furnace to be checked.

Fig. 64 gives the installation diagram of a thermocouple for measuring the temperature of the working chamber of a furnace. The hot junction of thermocouple *1* is installed in the furnace at the place where it is required to measure the temperature.

Determination of Masout and Gas Consumption. The consumption of masout can be measured by measuring tanks. This is the easiest method, but it is clumsy and inaccurate. More frequently *oil flow gauges* are employed for measuring the consumption of masout. Oil flow gauges operate on the principle of causing the liquid masout

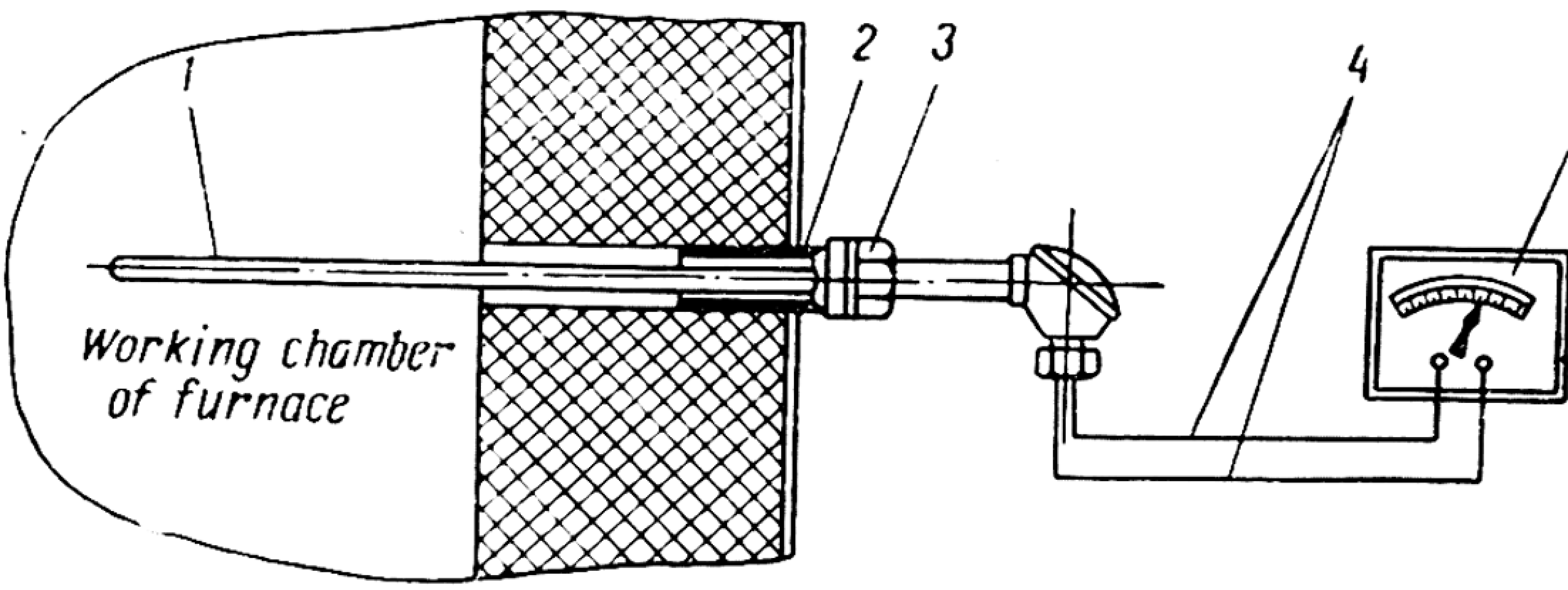


Fig. 64. Scheme of installation of thermocouple:
1) thermocouple; 2) tube; 3) coupling; 4) wires; 5) galvanometer; 6) furnace working chamber

to fill a drum of definite volume, from which it then flows. The number of drums filled is recorded by a special counter, and this indicates the amount of liquid which has flowed through the instrument.

In addition to the above-mentioned instrument, so-called *flowmeters* are employed for measuring the consumption of masout. They operate as follows: the masout, flowing through this instrument, rotates a small wheel with vanes; the axis of this wheel is, through a system of gears, connected to a counter, the scale of which indicates the consumption of masout. These instruments are installed in the pipes through which the masout is delivered and measure its flow. The consumption of gas is also measured by instruments indicating the consumption in units of volume (cubic metres).

Automatic Control. Automatic temperature controllers are employed for maintaining constant preset temperatures in heating furnaces. They automatically control the proportion of air and fuel to correspond with a preset temperature, thereby ensuring more reliable conditions for the combustion process than manual regulation.

Fuel consumption thermoregulators operate as follows: thermocouples, as we already know, generate electric current on being heated. The current generated by the thermocouple of a fuel consumption thermoregulator drives a servomotor, which adjusts the position of a throttle valve installed in the fuel delivery pipeline. When the temperature in the working chamber of the furnace rises above the permissible, the servomotor slightly closes the valve, thus reducing the amount of fuel being delivered; similarly, when the temperature falls, the servomotor slightly opens the throttle valve, thus increasing the fuel delivery.

The air delivery is regulated by a similar throttle valve installed inside the air line and connected with that in the fuel line. Both valves are adjusted so that, on turning the throttle, the cross-secion of the pipes is proportionally changed, the ratio of the fuel to the air being delivered remaining constant.

FURNACE OPERATION AND MAINTENANCE

Newly built furnaces or furnaces which have been overhauled must always be carefully and thoroughly dried before being heated up. The *drying process* consists of air-drying, drying with a wood fire and heating up to working temperature. For air-drying, all the doors and dampers of the furnace must be opened; this enables the moisture of the furnace brickwork to evaporate partially which is facilitated by the circulation of air. The duration of the air-drying process depends on the furnace dimensions, condition of the masonry and the weather.

After air-drying, the furnace must be dried with a wood fire. Before proceeding to this operation, all dampers and valves of the gas and air lines must be closed and, if the furnace is masout-fired, the masout line must be disconnected. In gas- or liquid-fired furnaces, a wood fire is lit in the working chamber; in coal-fired furnaces—in the fire-box. In this case the doors and dampers are left open.

To obtain a better draught in the chimney, a fire must be lit at the chimney base before lighting the wood fires in the working chamber or fire-box. The fire is gradually made up and, towards the completion of this drying operation, the temperature in the working chamber of the furnace should be about 600°C.

After the furnace has been dried with a wood fire it can be heated up with the fuel on which it is to operate. The time required *to bring the furnace to its working temperature*, i. e., 1,300°C will depend on its dimensions. Half way through the heating-up period, when the furnace has reached a sufficient temperature, it is charged with the metal to be heated. During the heating-up process, the roof

must be constantly watched. The tie-bolts should be loosened to prevent the roof from bulging. Particular care must be taken when heating furnaces with roofs made of dinas brick, as dinas expands considerably on being heated. Thermocouples should be installed in several places of the furnace to control the drying temperature.

The difference between *firing furnaces* after short periods of closing down (rest days) and heating them up after repairs consists in the fact that in the former case the furnace is generally loaded with steel and, moreover, the furnace heats up quicker than after long shut-downs (after repairs).

Furnaces must always be heated up with a wood fire, no matter what fuel is employed for their operation; if the furnace is coal-fired, the fire must be laid in the fire-box; if it is gas- or masout-fired the fire must be laid in its working chamber, the masout or gas being turned on only after the temperature in the furnace has reached about 600°C. The speed of heating up the furnace should not exceed the permissible rate of heating the steel in the furnace.

Feeding the Fire-Box with Fuel. Feed the fire-box with small portions of coal (6-8 shovelfulls at a time); this will ensure uniform burning of the coal. Large lumps must be broken up into small pieces from 30 to 50 mm in size. The coal should cover the grate in an even layer; be careful to add each fresh portion of coal first of all to those places where the coal has burnt through. The thickness of the layers of coal will depend on the grade used and the design of the grate. In a semi-gas fire-box, the layer of coal should be at least 400 mm thick. If the fire-box has more than one stoke hole, and the furnace has several fire-boxes, the coal should be charged to each fire-box in turn, and not simultaneously.

To prevent the flame from bursting through the stoke holes of the fire-box, the primary air supply should be slightly closed down and the supply of secondary air increased each time fresh fuel is added. The coal should be spread over a bed of slag about 20-40 mm thick.

Stoking. Only the upper layer of the fuel should be stoked; in this way the fresh fuel will not be mixed with fuel which has partially burnt through. Parts of the grate choked up with slag must be cleaned with the aid of a poker. The frequency of stoking operations will depend on the quality of the fuel but, as a rule, never start stoking immediately after adding the fuel.

Cleaning the Fire-Box. Depending on the intensivity of the operation of the furnace and the quality of the fuel, the fire-box can be cleaned once every shift or twice every 24 hours. If the furnace has two fire-boxes, they must be cleaned in turn.

Fire-boxes should be cleaned in the following manner: 1) half an hour before commencing cleaning operations, allow the coal in the

fire-box to burn out completely without adding any more coal; 2) before cleaning, close the air supply and open the ashpit; 3) do not rake out all the embers from the fire-box but rake them into a heap in one half of the grate, clean out the slag and ashes, spread the embers over the cleaned half of the grate and remove the ashes and slag from the other half, after which spread the embers over the entire grate; 4) thoroughly clean out the ashes from the ashpit; 5) certain coals, on burning, form layers of slag on the fire-box walls; this slag should be broken up with a bar and removed; 6) after cleaning and making sure that the fire-bars are in good condition, cover them with fresh coal, turn on the blast and proceed with the operation of the furnace.

Regulating the Operation of the Fire-Box. One of the main duties of the fireman is to keep a watch on the air supply. In all cases, whether the furnace is working at an intensive or slow rate, the volume of the air supply must conform strictly to the amount of fuel being burnt, so as to avoid excessive surplus or insufficiency of air.

When operating a semi-gas fuel fire-box, the fireman has to look after and regulate the ratio of the primary and secondary air supplies. This must be done in accordance with the heating conditions and the intensity of the furnace operation. In addition, he must: 1) see that the fire-box doors are tightly closed, to prevent the flames from bursting out and cold air from being drawn in; 2) attend to the grate, prevent fuel from turning through and slag from clogging the grate; 3) see that the air dampers, valves and sliding doors are in good condition.

The maintenance of masout- and gas-fired furnaces includes the following operations: checking the atomisers or burners before starting them up. It is most important that they be properly centred in the furnace holes. The pressure of the gas in the pipe system must always be positive. All cocks, valves or dampers of the atomisers must be tightly closed. Before starting gas burners, all air must be expelled from the gas pipes.

Before starting up a furnace, it is highly important to blow out the gas line, as even the slightest trace of air in it may lead to the formation of an explosive mixture of gas and air, which, when the furnace is started, may cause pops and even explosions, and thus destroy the gas line. Gas lines must be blown out with steam and then with gas. Before lighting the burners or atomisers, the gas damper and the furnace charging doors must always be opened to allow any accumulated gases to escape from the furnace and also to weaken their action should they "pop".

Shutting-down a Furnace. In forging shops, furnaces are shut down either because of break-downs of hammers or presses, or on

rest-days and holidays, when the shops are closed. All shut-downs may be classified as:

1) Short shut-downs, lasting up to 2 hours; the chief task of the furnace operators in these cases is to maintain the existing temperature of the metal in the furnace and to prevent it from being over-heated or cooled. For this purpose, the supply of fresh fuel is reduced, all charging openings, sliding doors and valves are tightly shut, and the damper is slightly opened so as to reduce the suction of air;

2) Long shut-downs (from 2 to 8 hours). During these shut-down periods the supply of fuel to the furnace must be completely shut off, the damper closed, all charging openings and sliding doors tightly closed, and all slots, cracks, etc., closed with clay wherever possible;

3) Very long shut-downs (more than 8 hours). In these cases the metal is removed from the furnace and the working chamber and the fire-box of the furnace thoroughly cleaned; all dampers are closed and the supply of fuel is shut off.

FORGE FURNACE OPERATION SAFETY ENGINEERING

Forge furnace operators must observe all safety engineering rules. Before being allowed to operate a furnace, workers must be thoroughly instructed in these rules. Moreover, furnace maintenance instructions based on safety engineering rules must be hung in a visible place near the furnace.

The furnace maintenance instructions and safety rules depend to a considerable degree on the furnace design and the fuel on which it operates. Gas-fired furnaces demand special attention, as this fuel contains poisonous gases (carbon monoxide, hydrogen sulphide, etc). Moreover, gas and air always form explosive mixtures.

However, there are certain *general safety rules* for operating forge furnaces, which, depending on the furnace design and local conditions of operation, need to be specified to a greater degree. They are:

1. All moving mechanisms (pushers, etc.) must be properly guarded.

2. The furnace must be equipped with screens, water-cooled frames and sliding doors, water screens, etc., to protect personnel from flames and heat radiation from the charging openings and fire-boxes.

3. Exhaust hoods must be installed over the furnace for collecting and discharging any products of combustion escaping from the charging openings.

4. To improve working conditions furnaces must be equipped with air showers.

5. All gas pipes must be leak-proof, so as to prevent the possibility of gas-poisoning during the operation of gas-fired furnaces. All joints must be welded. Flanged joints on gas lines may be permitted only for connecting valves; tarred asbestos cord gaskets must be inserted between the flanges of each flanged joint; and all gas lines must be periodically checked for leaks, all places which arouse suspicion being carefully checked with a soap solution which, in the case of leaks, will form soap bubbles. The welding of working gas lines must be executed according to special instructions, one of the obligatory conditions of which must be a positive pressure in the gas line.

6. Before lighting burners or atomisers, all charging openings, sliding doors and dampers must be opened and the furnace thoroughly aired. Otherwise, after the furnace is shut down gas or masout may leak through the burners into the furnace where, on mixing with the air, it will form an explosive mixture and thus create the danger of an explosion when the burners or atomisers are lit.

7. Burners or atomisers must always be lit with a torch attached to a long rod. When doing so, the worker must always stand to one side of the burner or atomiser, so as not to be injured should the flame escape.

8. No persons should be allowed to stand opposite the charging openings when the burners are being lit, owing to the danger of flames escaping.

9. Burners must be lit as follows: a) a burning torch is first applied with the aid of a long rod to the nozzle of the burner; b) only a small amount of gas is first supplied to the burner and, after it has been ignited, the volume of gas is gradually increased until it burns with a stable flame; c) air is added gradually, adjusting the proportion of gas and air until complete combustion of the gas is attained.

10. If, for any reason, the burner dies out on being lit, first the gas and then the air supply should be immediately cut off. Then, after the furnace has been aired the burner may again be lit.

11. On shutting a furnace down, the gas supply should be cut off before the air supply.

12. Should a break-down occur in the air supply during the operation of the furnace the gas or masout supply should be immediately cut off. Masout-fired furnaces are less liable to explosions than gas-fired furnaces; however, if the masout is delivered into a hot furnace before the air is turned on, it will evaporate, and masout vapours, on mixing with the air in the hot furnace, will form an explosive mixture.

13. The following rules must be observed when igniting atomisers:

a) The wood stacked in front of the atomiser should be ignited with a torch and allowed to burn for 10-20 minutes; in the absence

of a wood fire, a piece of hot metal should be placed in front of the atomiser;

b) Open up the air supply, after which the masout supply to the atomiser should be turned on, gradually increasing the air and then the masout until the flame is normal. If the furnace is equipped with several atomisers, they must be started up one after another;

c) In furnaces equipped with top and bottom burners or atomisers, the bottom rows must be ignited first, the top rows being ignited only after the temperature in the furnace has reached 600-650°C.

14. Never cool hot furnace hearths at high temperatures (1,000-1,200°C) with a stream of water, as this may result in severe burns to the furnace operators.

15. It is strictly forbidden to walk on the roofs of furnaces in operation. Should it be necessary to inspect a roof, or make repairs to a hot roof, the roof of the hot furnace should first be covered with planks, over which it is permitted to walk.

16. Never attempt to extinguish burning masout with water, as this may lead to a fire. Burning masout must be extinguished only with dry sand.

CHAPTER V

HEATING STEEL FOR FORGING

THE IMPORTANCE OF HEATING STEEL IN FORGING PRACTICE

If a piece of steel is heated, it becomes softer and its tensile strength is reduced, and, at the same time, its plasticity, and, consequently, its malleability, are increased.

As a result of improper heating practices and insufficient furnace productivity, a considerable loss of efficiency of forging units can still be observed in a number of forging plants, because of the time lost in waiting for the steel to reach the required temperature. Moreover, this so-called heating waiting time is sometimes included in the time specified for producing the forging. But innovators in industry have proved that, by improving the organisation of furnace operations, the time lost by forging units—the so-called "hot-metal waiting time"—can be completely eliminated.

As a rule, the productivity of a furnace should be from 15 to 20 per cent greater than that of the forging unit with which it operates, so as to be able to "speed up" the latter.

Heating the metal is one of the *main operations* in forging practice and is considered as being of equal importance with the forging operation itself. Proper heating and forging result in the *lightening of the work* of blacksmiths and forge hammer operators and ensure *high efficiency* of the forging installations. At the same time, power (steam, compressed air and electricity) and fuel *can be economised*, ensuring *high quality* of the forgings and reducing their cost.

CHANGES IN THE PROPERTIES OF METALS ON HEATING

Apart from the structural transformations which occur in metals on heating, their mechanical and physical properties also change. The chief object of heating a metal is to give it the required mechanical properties.

The plasticity of steel does not increase uniformly on heating. The plasticity of low-carbon, medium-carbon, low-alloy and medium-alloy steels falls when they are heated from 200° to 400°C, and that

of high-alloy steels on heating to 700-850°C. But, if heated above 600-750°C, the plasticity of steel, depending on its grade, greatly increases. At temperatures above 600-850°C (depending on the grade of steel) the plasticity of steel becomes so great that internal stresses and cracks do not occur.

The most important physical property of steel as concerns the heating process is its thermal conductivity. The *thermal conductivity* of a substance is its ability to conduct heat from a part at a high temperature to a part at a lower temperature. The higher the thermal conductivity of a substance, the greater will be the amount of heat which will penetrate from its surface to its core in a unit of time (hour) and, therefore, the less time will be required for heating it. The value of thermal conductivity is expressed by means of coefficient of thermal conductivity.

The *coefficient of thermal conductivity* of any substance is that amount of heat, in calories, which it can transmit per hour through a unit thickness (1 metre) across a unit area (1 sq. metre) for a unit difference of temperature (1°C). It is expressed as large calories per metre per hour (Cal/m/hr°C) and is indicated by the Greek letter λ. Thus, if we say that the coefficient of thermal conductivity of steel is 36 Cal/m/hr°C, we mean that 36 large calories of heat will be transferred per hour through a plate of steel 1 metre thick and 1 sq. metre in area for every 1 degree of difference in temperature between its sides.

The coefficient of thermal conductivity is determined by experiment for each substance, and varies greatly for different materials and grades of steel. Thus, the thermal conductivity, λ of pure iron is 60 Cal/m/hr°C, while that of grade 30 steel, is 38.2 Cal/m/hr°C. The coefficient of thermal conductivity of steel depends on its chemical composition, temperature and the treatment which it has undergone. The fewer alloying elements there are in the steel, the greater will be its thermal conductivity; its thermal conductivity falls with an increase in its carbon content. Moreover, the thermal conductivity of alloy steels is less than that of carbon steels.

The thermal conductivity of steel also changes with its temperature. Experiments have shown that, with a rise in temperature up to 800-850°C, the coefficient of thermal conductivity of ordinary carbon steels falls. Above 850°C, the coefficient of thermal conductivity of ordinary carbon steels increases slightly. The thermal conductivity of alloy and special steels changes during their heating depending on the alloying elements and their content in the steel. Investigations have established that the thermal conductivity of high-alloy chrome-nickel steels increases with an increase in temperature.

The *method of working the metal* also influences the thermal conductivity. Forging, rolling and, in general, all kinds of pressure working of steel increase its thermal conductivity. The thermal conductivity of cast steel is less than that of forged or rolled steel.

OXIDATION AND DECARBURISATION OF STEEL

On being heated in a furnace, the surface of steel, like that of any other metal, becomes covered with a layer of oxides, called *scale*. As the steel becomes hotter, the thickness of the layer of scale increases, until it begins to fall away to combine with the material of the hearth (if the latter is lined with fire-clay brick); this leads to the formation of so-called slag deposit. Part of the scale sticks to the surface of the steel. During the forging process, the oxidation of the steel continues, as the red hot steel is subjected to the action of the surrounding air.

Heating thus leads to a certain loss of metal, or the formation of scale due to oxidation of the metal. This loss is called *waste*, and it is necessary to distinguish between waste due to heating (furnace waste) and waste during forging (forging waste). There exists the widespread opinion that waste occurs mainly during the heating process in the furnace, and that forging waste is insignificant. But investigations have established that the loss of metal due to scale forming outside the furnace is considerable and in some cases is greater than furnace waste.

Waste results in considerable losses in production and leads to a considerable loss of steel together with the scale. During the production of forgings up to 3 per cent and more of steel is lost as scale during one heat; but this is by no means all the losses caused by waste. The scale remaining on the surface of the stock is pressed into the metal when it is forged, thereby lowering the quality of the surface of the work and reducing its tensile strength. During stamping the scale, falling into the die impressions, alters the dimensions of the forging and reduces the life of the die itself.

It is impossible to avoid waste when heating steel in flame forge furnaces; however, those heating conditions should always be sought which ensure the formation of a minimum amount of scale and, moreover, of a scale which can easily be detached from the surface of the stock without being forged into the steel. For this reason blacksmiths must understand the essence of the scale formation process, and must know how to prevent the loss of metal.

Iron commences to oxidise on its surface, and the process of oxidation gradually penetrates from the surface to the interior. The development of this process inside the stock can take place in the following manner:

1. The oxidising gas (O_2, H_2O, CO_2 and others) penetrates, or, as it is called, diffuses into the metal from the surface layer of scale into the iron; simultaneously, a similar diffusion of iron (Fe) takes place in the opposite direction. This process is accompanied by the following chemical reactions:

$$Fe+\frac{1}{2}O_2=FeO$$

$$Fe+H_2O=FeO+H_2, \text{ etc.}$$

2. Due to the different coefficients of expansion of scale (FeO) and iron (Fe), part of the scale falls away from the surface of the stock, and the new uncovered surface of iron is subjected to further oxidation.

3. At high temperatures the scale fuses and exposes the unoxidised iron of the stock, which in this way continues to oxidise. Due to its high temperature the iron becomes oxidised fairly rapidly.

The speed with which scale forms and its amount depend on the following factors: a) the temperature of the steel; b) the duration of the heating; c) the gas medium in which heating takes place; d) the composition and properties of the steel being heated; e) the shape and dimensions of the steel being heated.

The loss of steel increases with its temperature. Investigations have established that, if the speed of oxidation at 900°C is taken as unity, its speed at 950°C will be 1.25; at 1,000°C—2; at 1,100°C—3.5 and, at 1,300°C—7. The scale formation (oxidation) speed increases particularly sharply at 1,350-1,375°C, as at this temperature the scale begins to fuse.

The duration of heating the steel in the furnace also influences the amount of loss. The longer the steel remains in the furnace (at high temperatures and under other equal conditions), the greater the loss. Hence, it can be concluded that, in order to reduce losses of steel, it should be held at high temperature as little as possible.

The furnace atmosphere is another important factor which determines the amount of loss of steel. According to their action on steel, gases are classified as: oxidising, reducing and neutral gases. Oxidising gases include: oxygen (O_2); carbon dioxide (CO_2), water vapour, or steam (H_2O) and sulphur dioxide (SO_2); reducing gases include: carbon monoxide (CO) and hydrogen (H_2), while nitrogen (N_2) is a neutral gas.

To a certain extent the influence of the furnace atmosphere on the steel depends on the proportion of oxidising and reducing gases. As we know, the products of combustion include: CO_2, H_2O, N_2, O_2 and, sometimes, CO. The oxygen content of the products of combustion depends on the coefficient of surplus air employed for burning the fuel, while the CO content depends on the degree of

incomplete combustion. As a rule, furnace gases are nearly always oxidising. In the working chamber of the furnace the products of combustion cannot form a neutral atmosphere, still less a reducing atmosphere. For the atmosphere in the working chamber to be neutral or reducing, the products of combustion should have a high content of reducing gases—hydrogen and carbon monoxide, which, when burning fuel in heating furnaces, is impermissible.

The formation of scale depends to a large degree on the composition of the steel. Aluminium, chromium, silicon, tungsten and copper in steel retard the oxidation of its surface, as, on being heated, the scale forms a dense layer which firmly adheres to the surface of the steel and thus protects it from further oxidation. All grades of alloy steel (all other conditions being equal) are less liable to oxidation than carbon steels.

Consequently, the following conditions should be observed, *in order to reduce the loss of metal as waste* entailed when heating steel in forge furnaces:

1. Heating conditions should provide for the steel to remain as little time as possible in the furnace at high temperatures (above 900-1,000°C), at which maximum oxidation takes place. In this case the furnace will operate at high heating rates, and the loss of steel due to waste will be reduced. Thus, all the conditions necessary for high furnace productivity will lead simultaneously to a reduction in the loss of steel.

2. Ingots must be charged into and discharged from the furnace at uniform rates and continuously, without being held unduly long in the high-temperature zones. The best method is that of charging one piece of stock into the furnace simultaneously with the discharge of a previously heated piece.

3. The combustion process should be conducted so as to ensure the minimum possible free oxygen content in the products of combustion. Combustion must take place with a minimum surplus of air; at the same time, complete combustion must be ensured.

4. The furnace must be well packed and, at the same time, in order to avoid the suction of air, a slight positive pressure must be maintained on the furnace hearth.

5. The hearth of the furnace must be lined with basic materials, i. e., magnesia, chrome-magnesia and talc bricks.

This will exclude all possibility of the formation of low-temperature fusing compounds of scale with the hearth lining and the formation of fusable slag; the furnace will operate with what is called a "dry" hearth.

At high temperatures the oxidation of the steel is accompanied by its decarburisation. The *decarburisation* process consists in the reduction of the carbon content at the surface of the metal—the

carbon burns away. Decarburisation reduces the mechanical properties of steel. When decarburised, tool steel becomes soft, and tools manufactured from such steels have a short life. Experiments have shown that steel, on being heated, is first decarburised and then begins to oxidise, i. e., the decarburised layer of the steel is always to be found below the layer of scale. The degree of decarburisation increases with the temperature of the steel.

Decarburisation also depends on the chemical composition of the steel. The greater the carbon content, the higher the degree of decarburisation of the steel. Aluminium greatly promotes decarburisation, as does chromium, whereas manganese retards it. Silicon, nickel and tungsten have no effect on decarburisation.

OVERHEATING AND BURNING OF STEEL

If steel is heated beyond the upper critical point A_{C_3} and its temperature raised still further, a growth in the size of its grains can be observed under a microscope. The higher the temperature, the more energetic will be the growth of the grains, and, the longer the process of heating the steel to a given temperature the coarser the grains will be. Steel with excessively coarse grains is called *overheated* steel.

When forged, overheated steel will tear and crack, especially at the corners of an ingot or piece of stock, and its fracture will have an extremely coarse structure which can be seen with the naked eye. Overheating depends on two factors: the temperature and duration of the heating of the steel.

From the practical experience of forge furnace operation, it is well known that if an ingot or piece of steel is held in a furnace at high temperatures (for instance, in the soaking section of a continuous furnace) longer than usual, such an ingot or piece of steel will, on forging, display tears due to overheating. On the other hand, ingots held for a shorter time at the same temperature will forge quite normally.

Thus steel can be overheated at any temperature above the upper critical point A_{C_3}, the degree of overheating at any given temperature depending on how long the steel is held at this temperature.

Overheated steel can be improved by subsequent annealing, i. e., by slow heating to a temperature 10-30°C above the critical point A_{C_3} and subsequent slow cooling.

If a heated piece of steel is allowed to remain for a considerable time in the furnace at a high temperature, it will be burnt. *Burning of steel* is due to the oxygen of the furnace gases penetrating from the surface of the steel to its interior, oxidising the grain boundaries with the consequent fusing of the substances formed between the coarse grains. As a result, thin films are formed be-

tween the grains of the steel, contact between the grains is broken and the steel becomes weak; large cracks appear on the surface of the work, which breaks into pieces. Any further heating will lead to the fusing or destruction of separate sections of the work.

Burning depends chiefly on the heating temperature, the composition of the furnace gases, and the duration of heating the steel at high temperatures. Burnt steel cannot be rectified; such stock is usually rejected as scrap and the remaining metal can only be utilised as scrap for open-hearth furnaces.

To avoid burning, the following main conditions must be observed when heating steel:

1. The fuel should be burnt with the least coefficient of surplus air so as to ensure the absence of free oxygen in the furnace gases.
2. The stock should not be loaded on to the hearth in piles, but in such a manner so as to ensure the circulation of the furnace gases completely around it, without the flame of the burners or atomisers impinging directly on the surface of the stock being heated.
3. The furnace should be loaded with just enough steel to ensure the forging of one piece of stock while the next piece is being brought up to forging temperature in the furnace. The furnace should be charged by the "single piece" method, i. e., one or two pieces of stock are charged into the furnace simultaneously with the unloading of the same amount of stock. This will ensure the steel being held at high temperatures for just that amount of time necessary to bring it to a uniform required temperature. This, in turn, will ensure that overheating and burning of the steel are avoided.

FORGING TEMPERATURE INTERVALS

The difference between the initial and final forging temperatures is called the *forging temperature interval.*

For forging, metal must be heated to a temperature at which it will possess high plastic properties both at the beginning and the end of the forging process. Hence it follows that it is better to heat metal to higher temperatures, inasmuch as its plasticity (forgeability, or malleability) increases with the temperature. On the other hand, the danger of overheating limits the possibilities of increasing the heating temperature. In order to avoid burning, the temperature to which the metal is heated should be from 180-200°C below that at which burning sets in.

Steel, heated to 1,100-1,280°C (depending on its grade), becomes coarse-grained in structure. During forging, however, its grains are broken up and become finer. If the final forging temperature is high (above 900°), the grains will grow again during the process of cooling in the air; the cold forging will then have a coarse-grained

structure and low mechanical properties. If forging is finished at low temperatures (below 900°C), the grains will not grow when the steel is cooled owing to the low temperature. The cooled forging will then possess a fine-grained structure and high mechanical properties.

Thus, if the forging of a piece of steel is finished within a temperature interval of 900-700°C, depending on its grade, the forging will possess a fine-grained structure and, on the other hand, the higher the final forging temperature, the coarser the grain in the forging.

In order to ensure good-quality forgings, the forging process must be completed at a definite temperature established for each different grade of steel. Forging at temperatures below the established temperature (900-700°C) is not recommended as in this case the grain, instead of being broken up, will only be compressed (deformed), the steel will become *cold hardened*, as it is called, hard and brittle and as a result liable to cracks. Cold hardening can be eliminated by *annealing*, but cracks cannot always be eliminated and the forging may have to be rejected as spoilage.

From the foregoing, the following conclusions can be drawn:

1. Before forging, steel must be heated to the highest possible temperature which, in all cases, must be lower than that at which burning sets in. The burning temperature must be determined for each grade of steel by holding specimens for various time intervals at each temperature being tested. After determining the burning temperature for each grade of steel, the maximum heating temperature for forging can be determined; this temperature must be 180-200°C below the burning temperature.

Table 5

Forging Temperature Intervals for Various Grades of Steel

Grade of steel	Maximum heating temperature, °C (initial forging temperature)	Final forging temperature, °C	
		For preparatory operations	For finishing operations
Ст. 2, Ст. 3, 10, 15, 25	1280	800	700
Ст. 5, Ст. 6, Ст. 7, 40, 45, 50, 55, 15X, 20X, 35X, 40X, 30H, 40H, 40CX, 45X, 25XCMA, 30XH3M	1220	800	700
18XHBA, 18XHMA, 5XHM, 5XГM, 6XHM, 45XH	1200	800	700
У7, У8, У10, 7X3, 9X, 9X2	1150	850	800

2. Forging must be completed at a temperature at which further growth of the grain will not take place. This temperature is determined by experiment and is indicated in the technological (processing) sheet.

3. The temperature forging interval of certain widely used grades of steel ranges from 700° to 1,280°C. Table 5 gives the approximate forging temperature intervals for various grades of steel.

THE PROCESS OF HEATING STEEL IN FURNACES

Properly heating steel for forging presupposes:

a) Heating it to the required temperature uniformly throughout its entire cross-section;

b) Heating the steel at the maximum permissible rate without impairing its quality;

c) Heating the steel with the least possible loss of metal and with the minimum consumption of fuel.

In flame furnaces heat is transferred to the surface of the metal in two ways—by convection and radiation. By *convection* is understood the transfer of heat by the direct contact of continuously moving particles of furnace gases with the surface of the object being heated. As a result of this, the hotter particles of the furnace gases give up their heat to the colder surface of stock being heated.

By *radiation* is understood the transfer of heat through space from one body to another body at a lower temperature, the heat in this case being transferred as radiant energy which, falling on the surface of the second body, is completely or partially converted into heat.

In forge furnace steel is heated simultaneously both by convection and by radiation. Up to 600°C heating proceeds mainly by convection, only an insignificant amount of heat being transferred by radiation. At temperatures above 600°C, however, heat is transferred to the steel mainly by radiation, and not by convection. The greater the difference between the temperature of the steel being heated and that of the furnace gases, hearth, roof and walls of the furnace, the more rapid will be the transfer of the heat to the steel. The heat transferred to the metal by radiation and convection is absorbed by the surface of the stock or ingot. The further diffusion of heat inside the stock or ingot takes place as a result of the thermal conductivity of the steel.

As we know, the thermal conductivity of steels varies with their chemical composition. The more alloying elements in the steel, the poorer its thermal conductivity is. Inasmuch as thermal conductivity indicates the speed of the transfer of heat from the surface to the interior of the heated steel or ingot, it follows that low-car-

bon (mild) steels will reach a uniform temperature throughout their cross-section more quickly than alloy steels. The heating process in thick pieces of steel is different to that in thin pieces. The temperature is not distributed uniformly throughout the cross-section of heavy pieces of steel or ingots; the temperature at the centre is lower than that at the surface; moreover, the lower the thermal conductivity of the steel, the greater will be the difference between the temperature at the centre of the ingot or of the stock and at its surface. The more rapid the rate of heating and the larger the cross-section of the steel, the greater will be the difference between the furnace temperature and that of the surface of the ingot being heated.

This uneven distribution of temperature throughout the cross-section of an ingot or piece of stock gives rise to what are called *thermal stresses.* Thermal stresses are due to the fact that the outer layers of the steel, being at a higher temperature than its central portions, expand in volume to a greater extent than the latter. As a result, the outer layers of the metal of the ingot or stock strive, as it were, to separate themselves from the inner, cooler layers, which retard the expansion of the outer layer (surface) of the steel. Consequently, if an ingot is not uniformly heated throughout its cross-section, *compression stresses* will occur at the surface and *tensile stresses* in the centre; and it is these stresses which give rise to cracks during heating.

The process of heating stock or ingots can be divided into two periods: *the first period*—that of heating in the low-temperature zone—up to 500-700°C, and *the second period*—of heating in the high-temperature, or forging zone. The first heating period is very important as at comparatively low temperatures the plasticity of carbon and ordinary alloy steels, and the thermal conductivity of high-alloy steels is low. Large ingots or heavy stock, particularly of high-alloy steel, should be heated with extreme caution to avoid the formation of thermal stresses which may lead to cracks. For this reason, the heating should be effected as slowly as possible, and the furnace charging temperature of cold ingots, particularly of alloy-steel ingots, should not exceed 600-800°C. Stock of mild carbon steels and thin pieces of alloy steel (up to 100 mm thick) may be charged into furnaces heated up to the forging temperature.

The second heating period—that of heating in the high-temperature zone—is characterised by the high-heating rates. At temperatures above 500-700°C, carbon steels possess a good degree of plasticity and therefore the internal thermal stresses which arise during the heating of such steel cannot give rise to cracks in the ingot or stock. During the second heating period, care must be taken to avoid burning the steel. For this purpose, the temperature of the

furnace gases in box-type furnaces, in which steels are heated to high temperatures, must never be more than 100-150°C above the required temperature of the steel.

HOW TO DETERMINE THE DURATION OF HEATING STEEL

By the duration of the heating is understood the time necessary for uniformly heating an ingot or piece of stock to a definite temperature. There are many methods for determining the time for heating steel. The simplest formula, and one which gives values close to actual results, is that proposed by Academician N. Dobrokhotov.

He recommends the following formula for determining the duration of heating cold ingots or pieces of stock up to 1,200°C:

$$z = kD\sqrt{D} \text{ hours,}$$

where z— the heating time, in hours;

D—the diameter or length of opposite side of the ingot or stock, in metres;

k—a factor, equal to 10 for carbon steels containing up to 0.4 per cent of carbon, and 20—for alloy steels.

When determining the duration of heating by N. Dobrokhotov's formula, it must be remembered that this formula holds good only for the case when an ingot or piece of stock is heated from all four sides. In actual fact the position of ingots or stock on the hearth furnace will vary; for this reason the results obtained from the above formula must be multiplied by a factor, depending on the position of the stock in the furnace. These factors are given in Fig. 65. The time required for heating one piece of stock placed on the hearth of a furnace is taken as unity. For other positions, for instance, when round stock is loaded on the hearth of a furnace without spaces between them, the required heating time will be doubled. To ensure better utilisation of the furnace hearth, and to reduce the fuel consumption when heating round stock, the latter should be loaded onto the furnace hearth without any packing between them and the hearth and spaced at intervals of one half the diameter of the stock. Square and rectangular stock should be placed on packings; in this case, the stock will be "licked" on all sides by the furnace gases; the distance between the pieces of stock should be equal to the length of the side of the square.

Example. Determine the heating time for a piece of alloy steel stock 1 m in diameter. The stock is loaded on the hearth with spaces equal to one half its diameter.

Solution. According to the formula, $z = kD\sqrt{D} = 20 \times 1\sqrt{1} = 20$ hrs. This holds good if only one piece of stock is placed in the furnace and is heated on all sides by the furnace gases. In our case, how-

ever, three round pieces of stock are charged into the furnace simultaneously, the distance between each piece of stock being equal to one half its diameter (see Fig. 65). In this case the correction factor

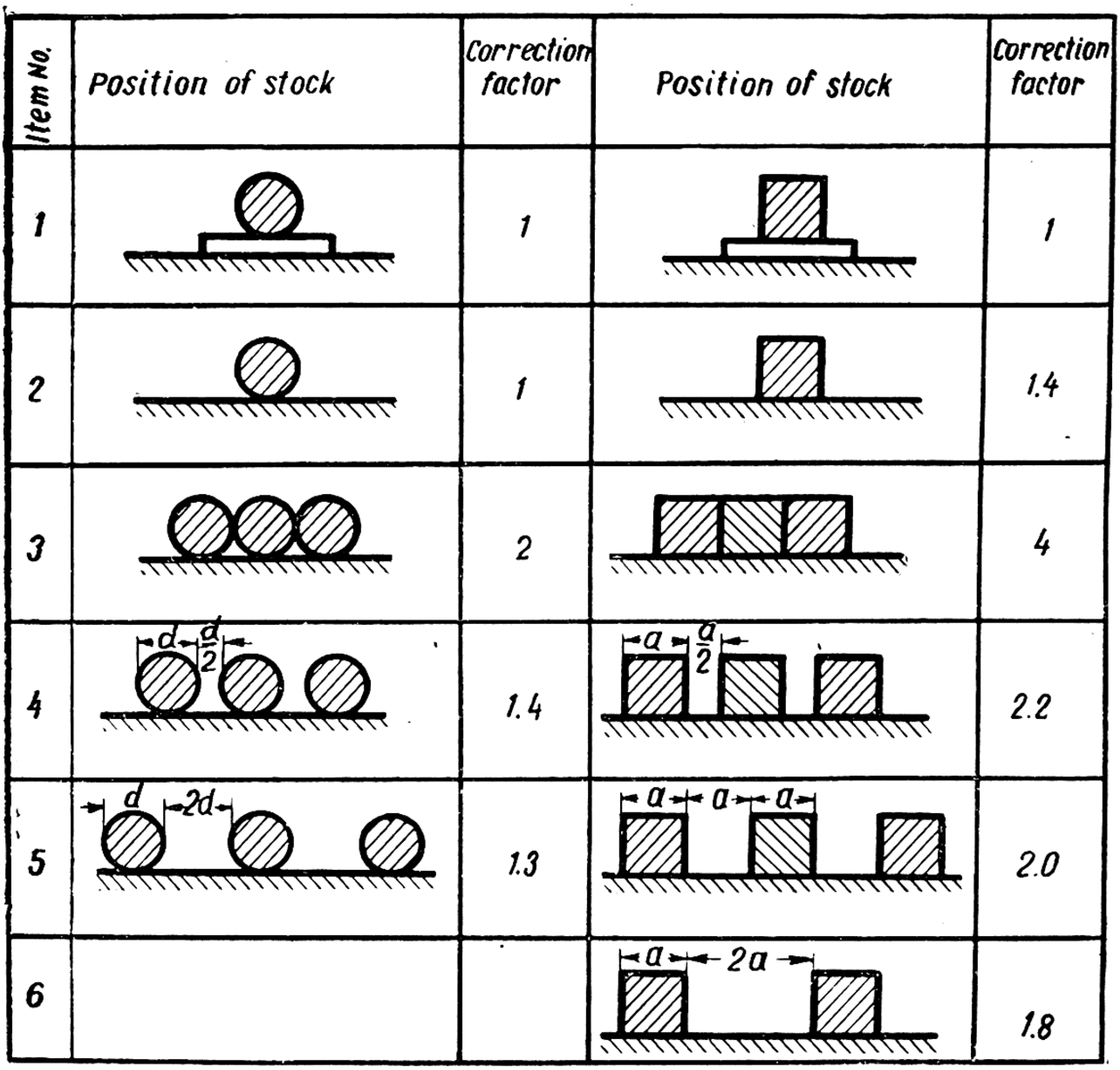


Fig. 65. The influence of the position of the stock in the furnace on the duration of heating

depending on the method of loading the stock on the furnace hearth, will be 1.4. Therefore the actual heating time will be:

$$z = 20 \times 1.4 = 28 \text{ hours.}$$

So far none of the theoretical methods of determining the duration of heating give results coinciding with data obtained in practice. The heating time usually is first of all determined by formula, and then found more exactly by practice. As a matter of fact, different factories make use of steel-heating tables drawn up on the basis of the prevailing conditions and the state of their equipment.

HEATING BY ELECTRIC CURRENT

The following two main methods of heating steel by electricity for forging and stamping are employed: contact and induction electric heating.

Fig. 66 shows the diagram of an installation for *contact electric heating* of forge stock. Stock *3* is held between contact holders *2* of a secondary low-voltage mains. The current, flowing through the stock, heats it to the required temperature as the result of the conversion of electric energy into heat energy. Alternating current of industrial frequency is mainly used for contact heating.

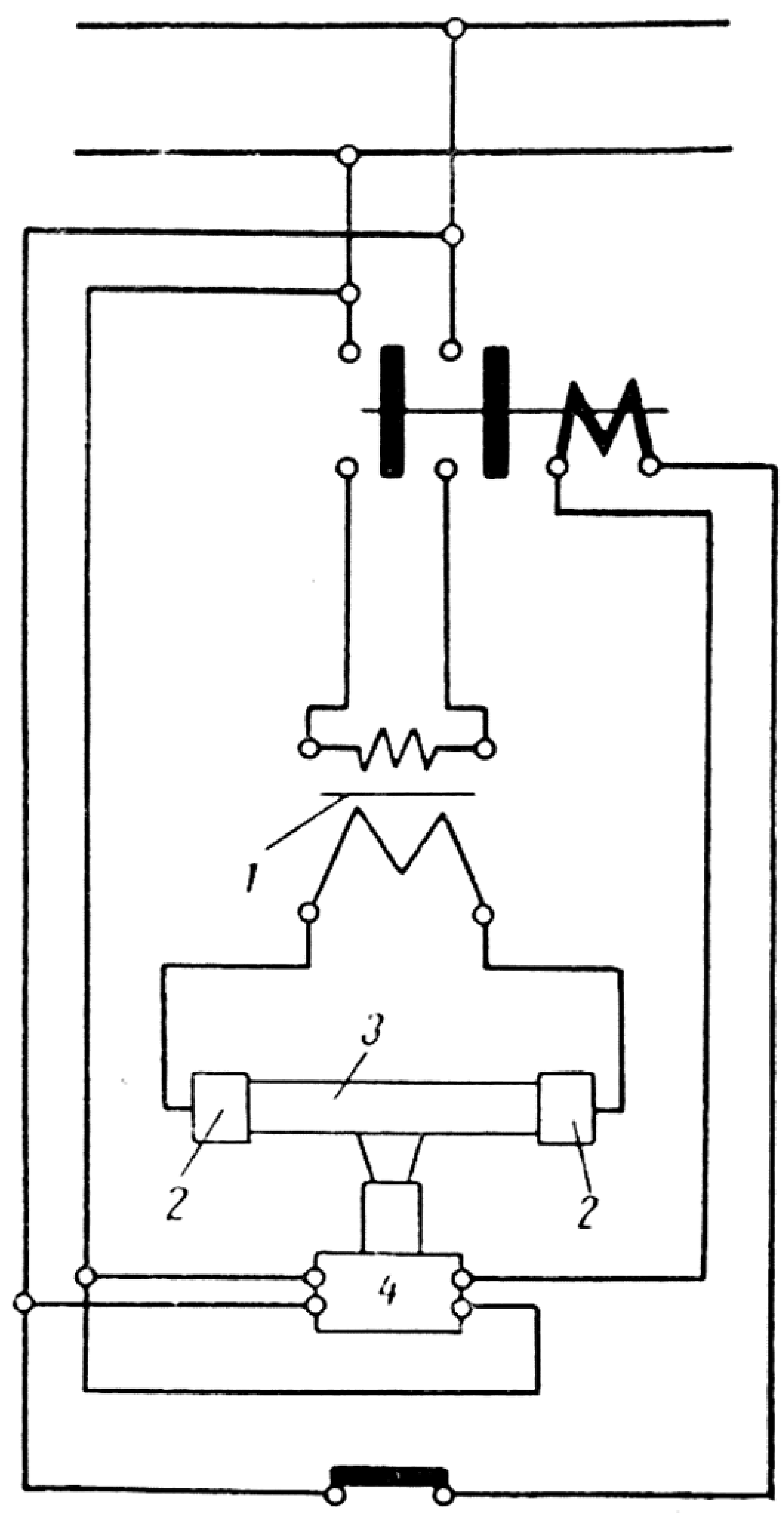


Fig. 66. Wiring diagram for the electric contact heating of forge stock:
1) transformer; 2) contacts for holding stock; 3) stock; 4) photometer (instrument for measuring temperature)

Stock is heated by this method uniformly throughout its entire cross-section; along its length, however, its temperature will vary; the temperature of the ends of the stock secured between the contacts will be below the required forging temperature. Contact heating is employed for heating stock from 18 to 70 mm in diameter; it cannot be employed for heating stock of stepped cross-section. Contact and induction steel heating methods are steadily displacing furnaces in serving high-productive forging units such as forging machines and forge-stamping presses. Reduced heating time cuts down losses of steel due to scale, and results in finer grain structure. This permits a higher temperature forging interval (deformation temperature interval) which, in its turn, increases the productivity of forge units.

The most progressive heating method in use to-day is the *induction heating method*. This method results in high speeds of heating and permits heating stock of stepped cross-section by electric current. Fig. 67 shows an induction apparatus for heating cylindrical stock. Stock *8* is inserted into the inductor along guides *4*. Alternating current of high or extra-high frequency is passed through coil *1*.

As a result of electro-magnetic induction, turbulent currents are generated inside the stock thereby heating it. For heating a piece of stock from 30 to 80 mm in diameter, an alternating current of

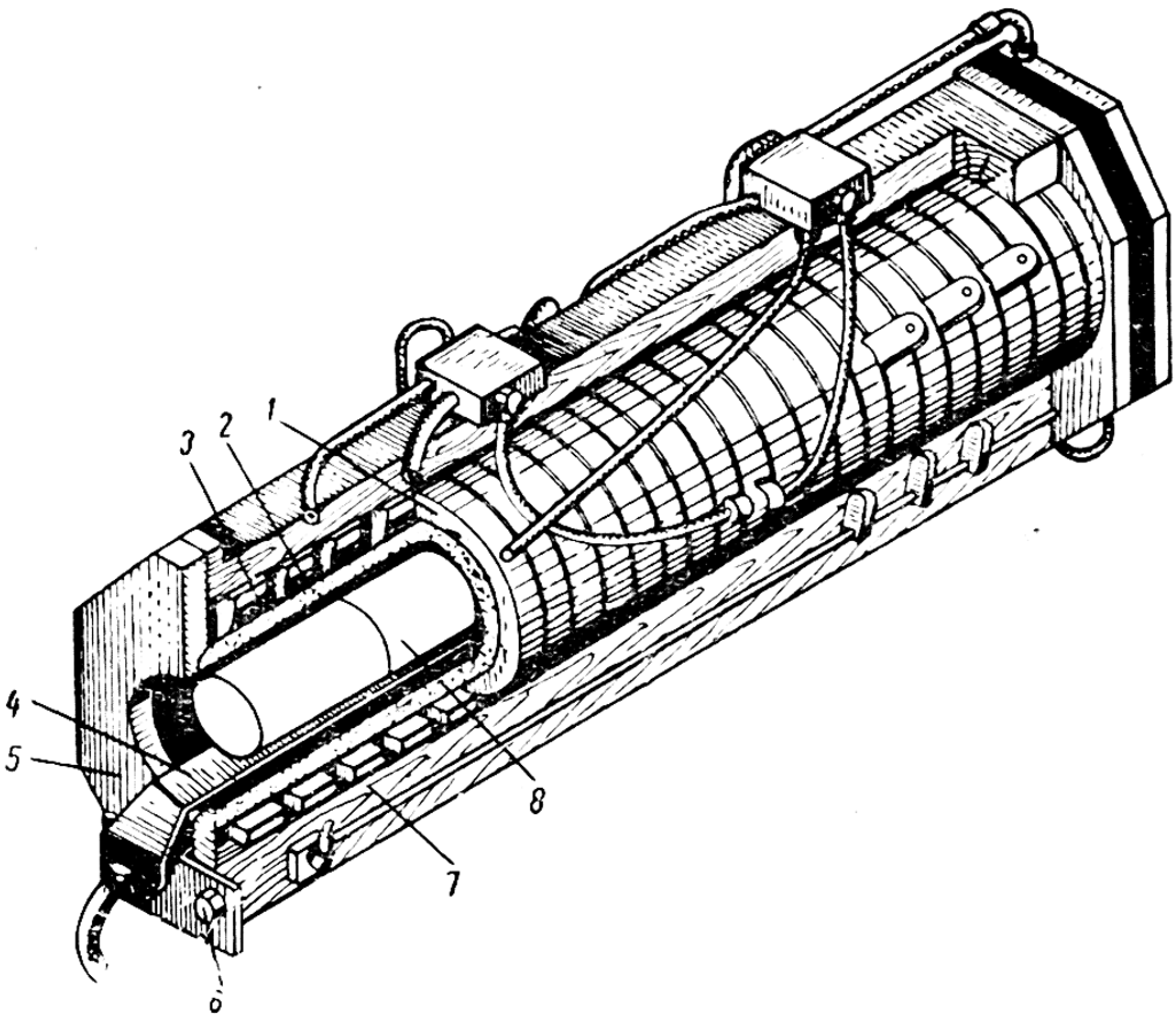


Fig. 67. Inductor for heating cylindrical stock:
1) coil of copper tube; 2) electrical insulation (micanite cylinder); 3) heat insulation (ceramic brick); 4) hollow heat-resistant steel guides; 5) asbocement plates; 6) brass bolts; 7) wooden beams; 8) stock to be heated

2,500 cycles per second is passed through the coil; and stock up to 150 mm in diameter is heated by an alternating current of 500-1,000 cycles per second.

The current must be of still lower frequency for heating stock of greater diameter, when ordinary alternating current, or so-called industrial frequency, is used.

CHAPTER VI

CHIEF HAND-FORGING OPERATIONS

GENERAL INFORMATION ON BLACKSMITH'S TOOLS

Blacksmiths have to perform all kinds of forging work, for which various tools and implements are needed. They use special tools and fixtures for hand forging.

The Anvil. The blacksmith's anvil is a heavy block of iron or steel on which the metal is forged. Anvils have to be very heavy so that hammer blows do not cause them to move. They are generally made of steel and weigh from 80 to 300 kilograms—usually, 150 kg. The top of the anvil, called the face, must be hardened and always smooth.

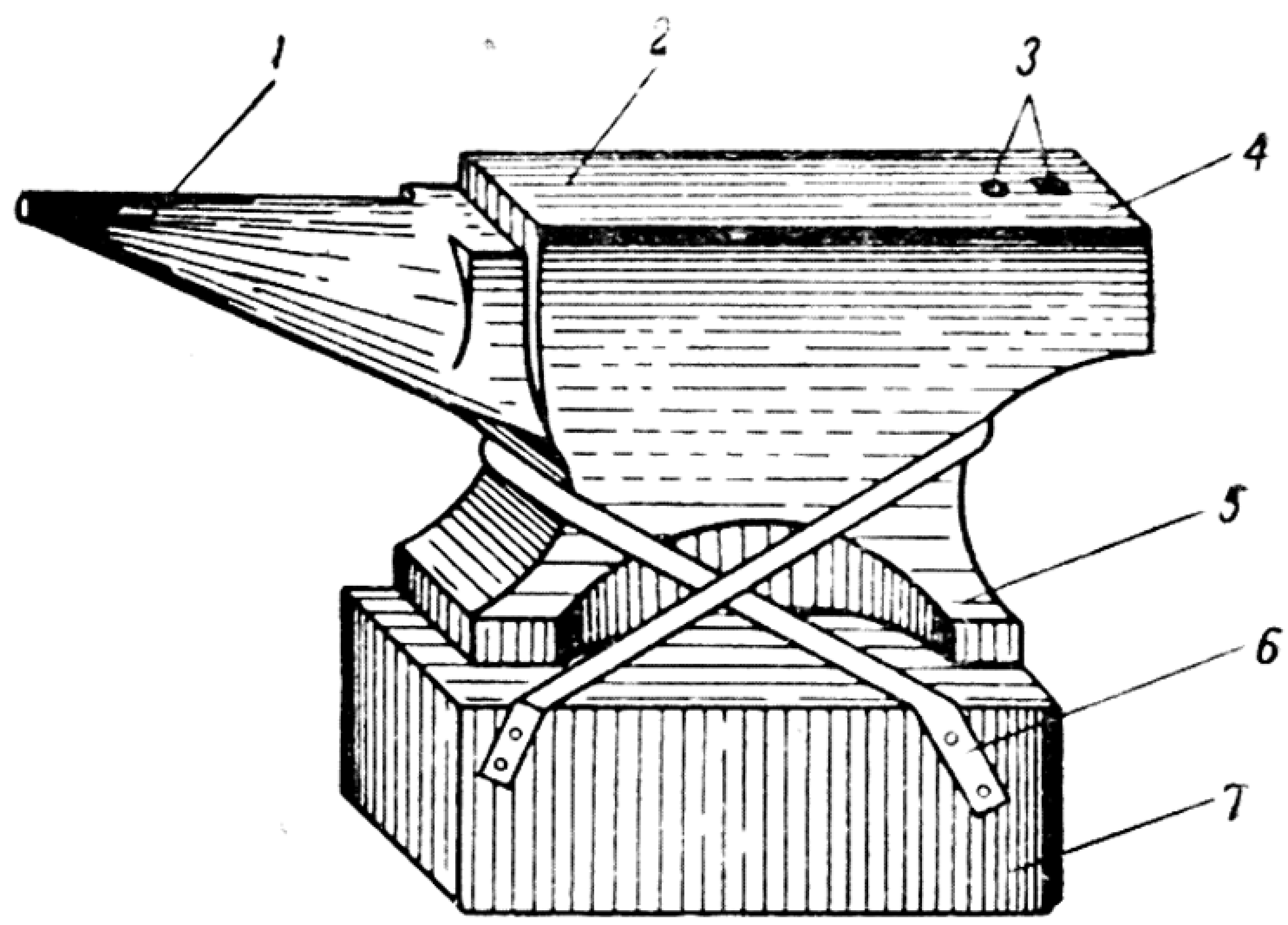


Fig. 68. Single-horn anvil

The blacksmith generally judges an anvil by the sound it gives when struck with a hammer. If a good anvil is struck with a hammer, the hammer will rebound, and the anvil will give a clear, sharp sound. A faulty, i. e., cracked anvil will give a dull sound. It is always easier to work on a good anvil than on an anvil which sounds dull.

The anvil is usually mounted on a heavy block of wood let into the soil, to which it is secured by spikes or clamps. Anvils should be set up at a definite height: standing upright beside it, the blacksmith should be able to reach its face with his finger-tips.

Fig. 68 shows an anvil. Projected from one side is horn *1* which is mainly used for bending forgings. The opposite end *4* of the anvil is rectangular and is called the tail; it is used to bend work at right angles. The anvil has four feet *5* at its base. These serve to secure the anvil to its foundation *7* with the aid of straps *6* or spikes. Forging operations of all types are performed on face *2* of the anvil.

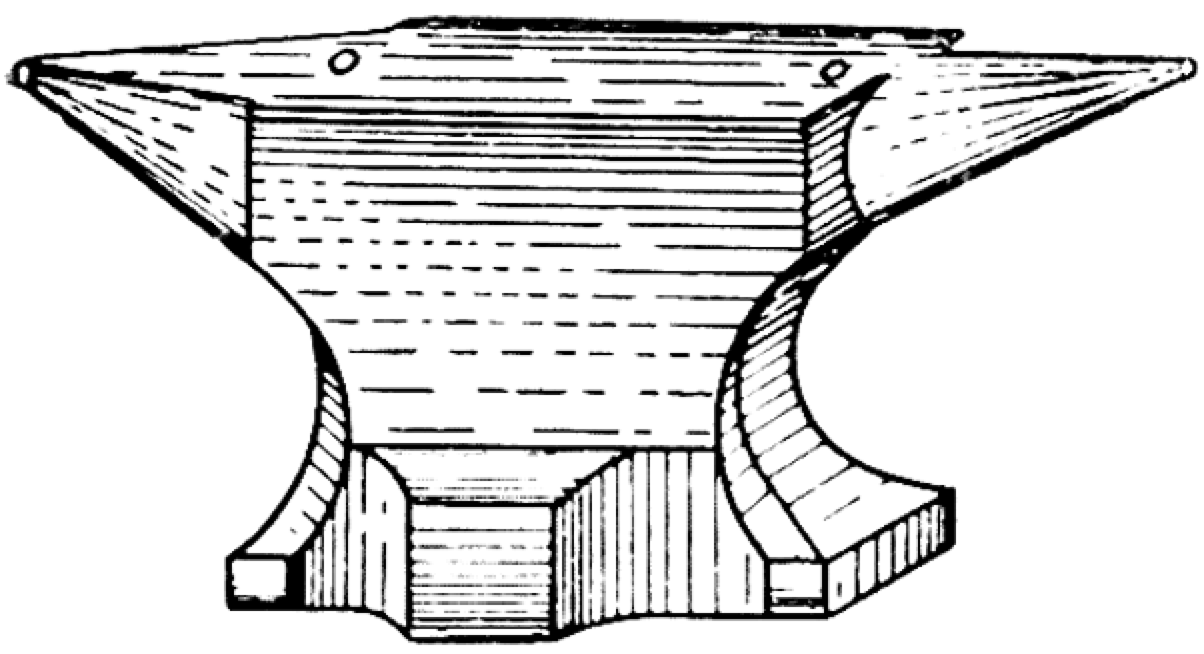


Fig. 69. Double-horn anvil

The tail of the anvil has two holes *3*—one round and one square. The round hole is used when punching holes and the square one—for securing various devices during the forging operations.

Two types of anvils are employed—the *single-horn anvil* which, as its name implies, has only one horn (Fig. 68) and the *double-horn anvil* (Fig. 69). Single-horn anvils are more frequently met with.

Tongs. Tongs are used for gripping and turning work during forging. They are made of carbon steel containing 0.3-0.4 per cent of carbon. Blacksmith's tongs consist of two bars secured by a rivet. Each bar consists of two sections: a short one, called the jaw, and a long one, the handle. The total length of a blacksmith's tongs varies from 475 mm to 650 mm, the length of their jaws being from 75 to 140 mm. Tongs are made in various designs to suit the different shapes and dimensions of the work being forged. If the blacksmith has no tongs of the required shape and dimensions in

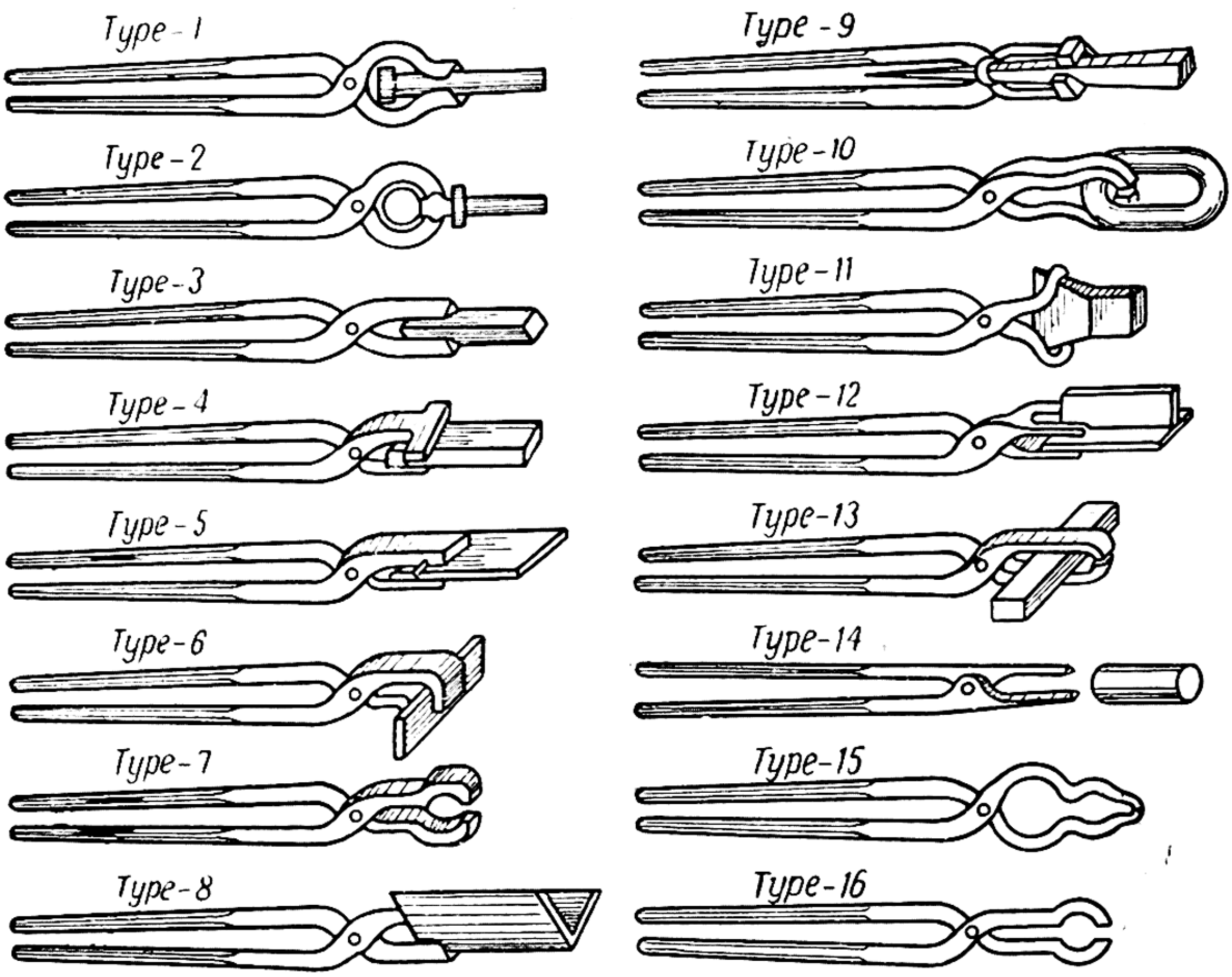


Fig. 70. Blacksmith's tongs

stock he can always adapt one of the tongs to suit the forging to be made. For this purpose he heats the jaws of a suitable tongs to a cherry-red colour, and then inserts one end of the forging between the jaws which he then hammers until they grip the work tightly.

When performing prolonged forging operations, or when forging heavy work, the blacksmith slips a ring, or stirrup, over the shanks of the tongs to keep them closed, and to lighten his work. Fig. 70 shows the most commonly used types of blacksmith's tongs.

Hand Hammers and Sledge-Hammers. In their work blacksmiths employ hand (blacksmith's) hammers, weighing from 0.5 to 1.5 kilograms (Fig. 71). These hammers are used for making light forgings. The blacksmith also uses the hand hammer to show his striker where to hit the forging. The handles of these hammers are made of strong tough dry wood, for instance, birch, maple, etc. They must be firmly attached and wedged inside the hammer head. The length of the handle is usually from 350 to 400 mm.

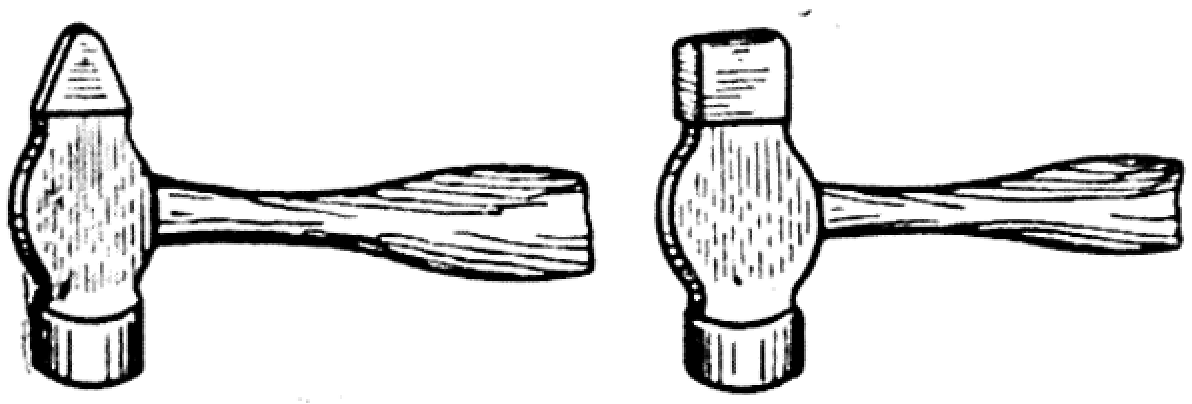


Fig. 71. Blacksmith's hand hammers

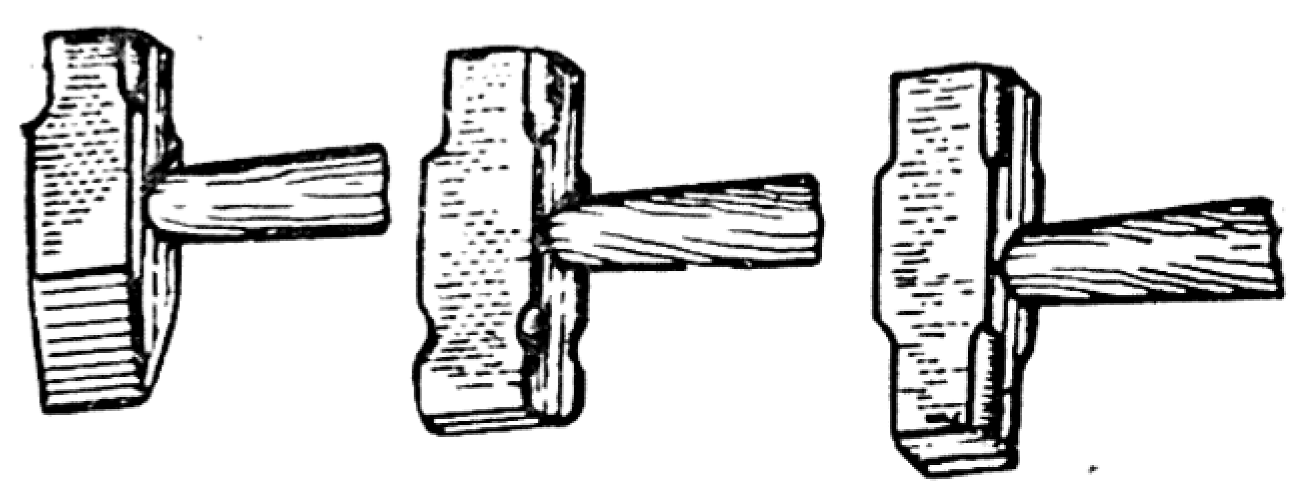


Fig. 72. Blacksmith's sledge-hammers

Sledge-hammers (striking hammers) vary from 2 to 10 kg in weight (Fig. 72), and are the striker's chief tool. The striking surface of a sledge-hammer must be slightly convex, smooth, and never lopsided. Sledge-hammer handles are made from 700 to 900 mm long; their length is selected to suit the blacksmith's arm and his height.

Measuring Tools. Blacksmiths employ simple measuring instruments for checking forgings in the process of work (Fig. 73).

Common calipers (Fig. 73, *a*) are employed for checking only one dimension of a forging. The blacksmith sets the caliper legs to the required distance and, while working, repeatedly checks the dimensions of the forging with the calipers set in this way.

Double calipers (Fig. 73, *b*) are employed for checking two dimensions of a forging. The blacksmith sets one pair of legs to one distance required and the second pair to the second distance required; he checks the dimensions of the forging while working with the calipers thus set.

Triple calipers (Fig. 73, *c*) are employed for checking three dimensions of a forging, and are set and used in the same way as double calipers.

Inside calipers (Fig. 73, *d*) are employed for checking the size of holes and recesses in forgings.

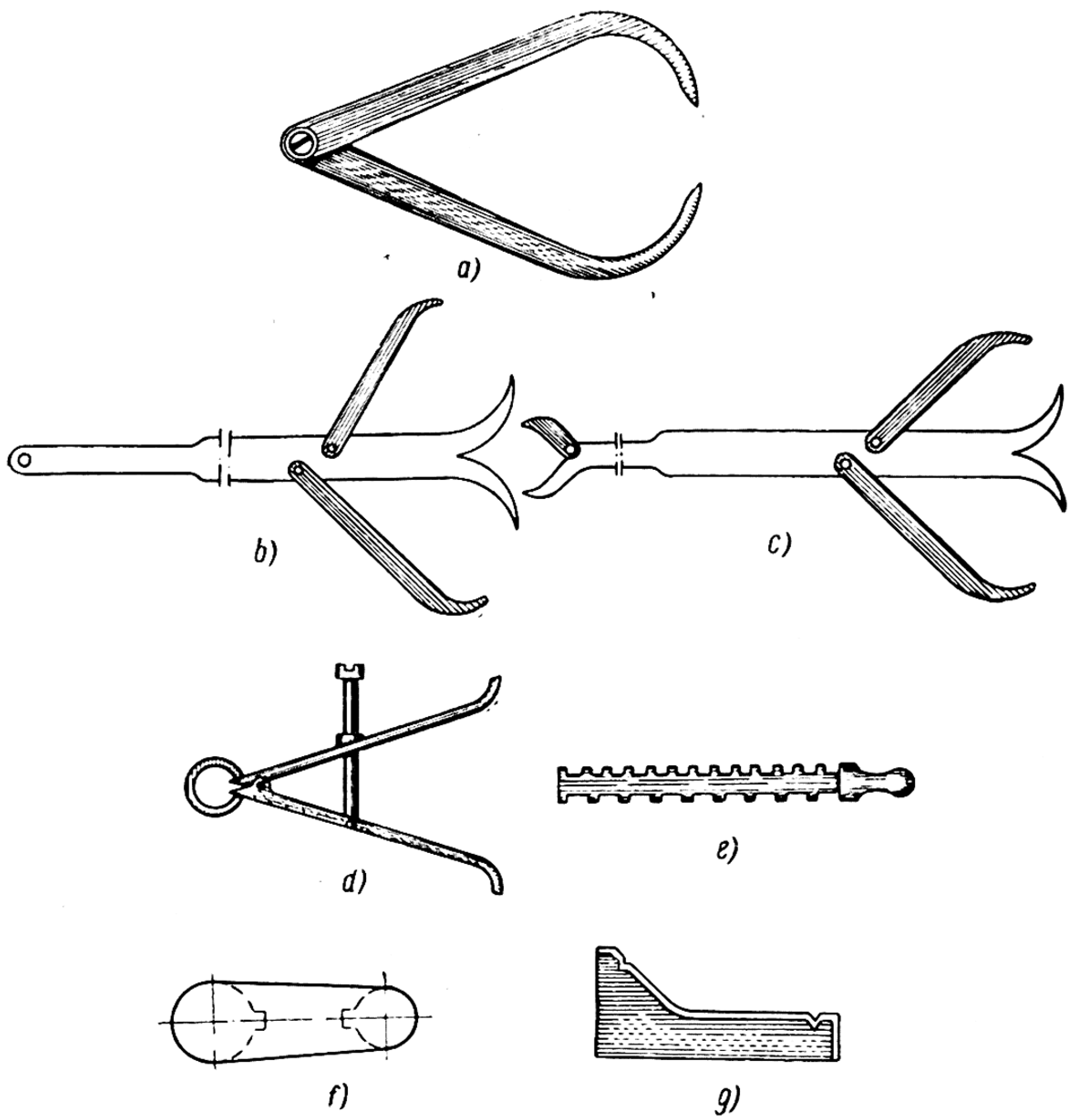


Fig. 73. Various types of measuring instruments

Gauges (Fig. 73, *e*) are employed for checking the thicknesses of bars and light forgings.

Templates (Fig. 73, *f*) are employed for checking the accuracy of the shape of intricate forgings. They are made by cutting a piece of steel plate to the shape and dimensions of the required forging; when checking forgings with a template, the latter is placed on the forging to be checked. Fig. 73 shows two templates — one (*f*) for check-

ing the profile of a lever, and a second (*g*) for checking the profile of a bracket. Templates must be employed only for checking the work for which they are made.

In addition to the tools mentioned above the blacksmith must also have a folding rule, a steel straightedge and a try-square, as well as other special tools. These tools will be described when the various operations entailed in hand forging are dealt with.

When making forgings, the blacksmith usually employs several measuring instruments simultaneously. For instance, suppose a *shackle is to be forged* (Fig. 74). This will entail several operations or passes as they are called. Before proceeding to the final operation the blacksmith will set his measuring instrument for checking the dimensions of the shackle at the dimensions indicated in the drawing. In this case he will use the following instruments:

1) Steel rule; he transfers the length *f* of the shackle (Fig. 74) to the steel rule with the aid of his folding rule, marking it off on the latter with a piece of chalk;

2) Triple calipers (see Fig. 73, *c*); he sets one pair of legs of the calipers to dimension *a*, the second pair—to dimension *b* and the third pair—to dimension *c*.

3) Inside calipers for checking dimension *c* (see Fig. 73, *d*); with the aid of his folding rule, he sets the legs of the inside caliper to dimension *c*.

In the process of forging, the blacksmith, using these three measuring instruments, checks the dimensions of the shackle by placing the corresponding instrument against the forging.

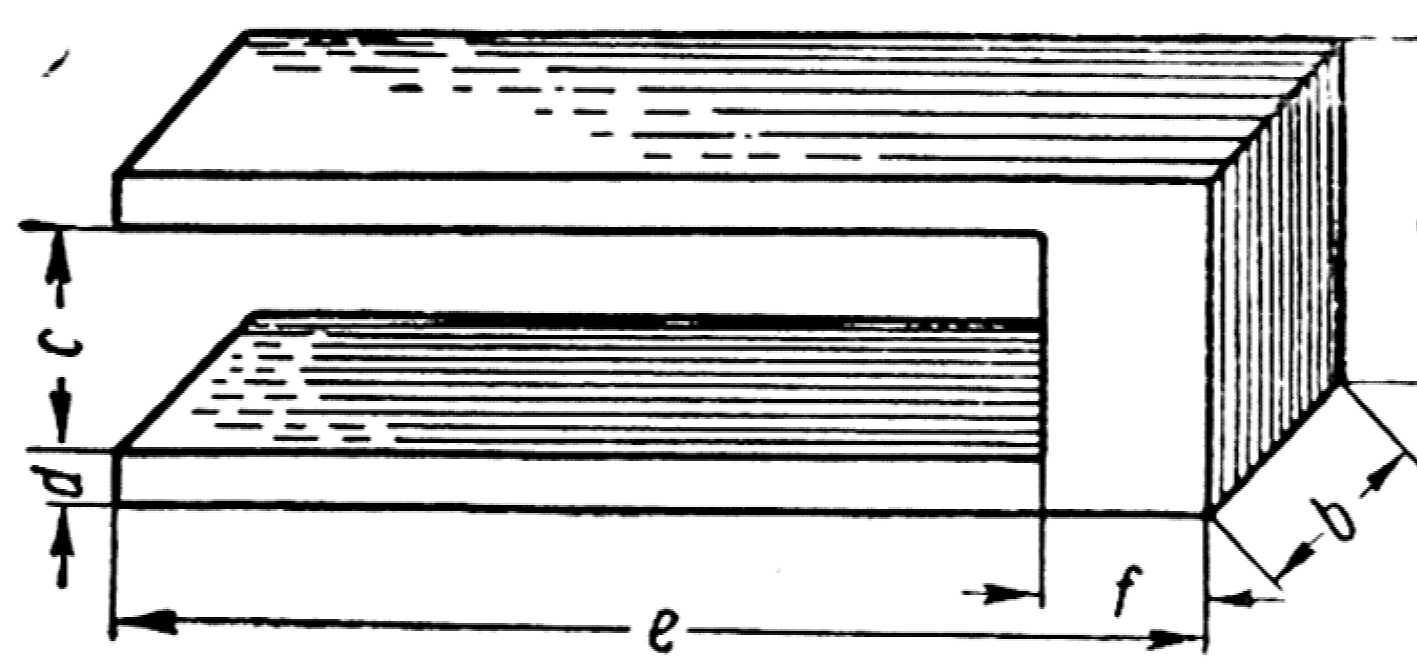


Fig. 74. Shackle

The proper care of tools and instruments lengthens their life, reduces the cost of their repairs and increases the productivity of the blacksmith's work. The chief rules for the maintaining of blacksmith's tools and instruments are: store them carefully, keep them free from dust and dirt, check them at regular intervals and repair them if necessary. Moreover, care must be taken to prevent the tools from overheating, as they soften, bend, and often become unfit for further use. They should be cooled in water as frequently as possible during the process of work.

The head of blacksmith's tools (i. e., the part of the tool which is struck with a hammer as, for instance, the head of a set, punch and similar tools) should never be hardened; otherwise heavy blows

may result in chips flying off and wounding the blacksmith. Before commencing work, always make sure that the handles are properly secured to hammers and sledge-hammers.

GENERAL INFORMATION ON HAND FORGING

When forging work by hand, the blacksmith grips the metal, heated to the forging temperature in a hearth or in a small furnace, with his tongs (which he holds in his left hand) and places it on the anvil.

His helper or striker hits the work with his sledge-hammer at the spot indicated by the blacksmith with the hand hammer, which he holds in his right hand. When he needs any tool (set, fuller, etc.), the blacksmith takes it in his right hand in place of the hand hammer, while the striker hits the head of the tool with the sledge-hammer.

If the temperature of the forging falls below the forging temperature specified for the given grade of steel, work on it must be stopped and the forging reheated to the required forging temperature before work is resumed. Sometimes a forging has to be reheated six times or more before it acquires its proper shape and dimensions.

In spite of the fact that blacksmiths, in the course of their work, have to make forgings of many different shapes and sizes, they always employ the same operations, but in varying order. In general only a few operations are used in forging, these may be called the *principal hand-forging operations*. They include: 1) drawing-out and fullering; 2) cutting; 3) jumping or upsetting; 4) bending; 5) piercing and punching holes; 6) twisting; 7) welding; 8) finishing.

Every blacksmith should always try to make forgings of high quality with the fewest number of passes and, consequently, to reheat his work as few times as possible. Making a high-quality forging with a minimum expense of physical energy and time depends on the blacksmith's skill. The work of a blacksmith is very complicated and demands great skill. While the stock is still in the hearth, the blacksmith should be visualising mentally the various operations which he has to execute on the heated steel. Only a poor workman puts his heated metal on his anvil with no clear idea as to what he intends to do first.

To avoid accidents, blacksmiths must observe the following *safety rules*:

1) Employ only those tongs whose jaws fit the shape of the forging;

2) See that the hand hammers and sledge-hammers are always securely attached to their handles;

3) Thoroughly clean the hot stock and anvil from any accumulations of scale with a steel brush or scraper; on no account should the anvil be cleaned with the hands, even when protected by gauntlets;

4) See that the anvil is never wet or greasy;
5) Never attempt to forge cold or burnt steel;
6) Keep his working place clean and tidy; never accumulate any refuse, forgings, hot cuttings or anything which may interfere with his work or lead to accidents;
7) Always work in working clothes as specified by the safety engineering rules.

Before commencing work the blacksmith must always:
1) See that his equipment is in good condition, remove all scale, water and grease from the anvil;
2) Select and prepare all the tools which he may need; see that they are in good condition; wipe all traces of water and oil from tools and instruments with a rag; and before commencing work warm up all tools which have to be struck;
3) See that he has the proper number of pieces of stock for his task. Check the stock and see that it is of good quality;
4) Put his working place in order.

During his work, the blacksmith must:
1) Use each tool only for the work for which it is designed;
2) Protect his equipment and tools from damage and regularly remove all scale from the anvil;
3) Never allow any forgings and waste material to accumulate around his working place; put all forgings and waste material in their proper place.

At the end of his work the blacksmith must always wipe his tools and instruments with a rag, put all his forgings and waste material in their proper place, and tidy the area around the anvil or hammer.

DRAWING-OUT AND FULLERING

Drawing-out is a forging operation during which the cross-section of a piece of stock is reduced and its length increased. During the drawing-out operation, the fibre of the metal is lengthened more or less uniformly throughout its entire cross-section.

In practice the *drawing-out operation* consists in hammering a piece of stock after it has been taken out of the hearth or furnace and placed on the anvil, either directly with a hand- or sledge-hammer, or with the aid of drawing-out tools. The stock will become thinner where it is struck, but will at the same time increase in length and width. It is then turned through 90° (placed on its edge) and its drawn-out portion hammered in the same way, thus reducing its width and increasing its length. After each blow, the forging must be turned through 90° and moved backwards and forwards all the time; in this way, a piece of metal can be drawn out to any required length and cross-section. If it is required to increase the length and width of a piece

of work, it must be placed on the anvil and struck with a hand- or sledge-hammer; if only the length is to be increased, a flat or round-faced smoother must be placed on the work and then struck with a hand- or sledge-hammer. The drawing-out process will proceed faster if narrow-faced tools are used (Fig. 75). After being drawn out, the surface of the work must be smoothed out with a tool called a *smoother*, or flatter.

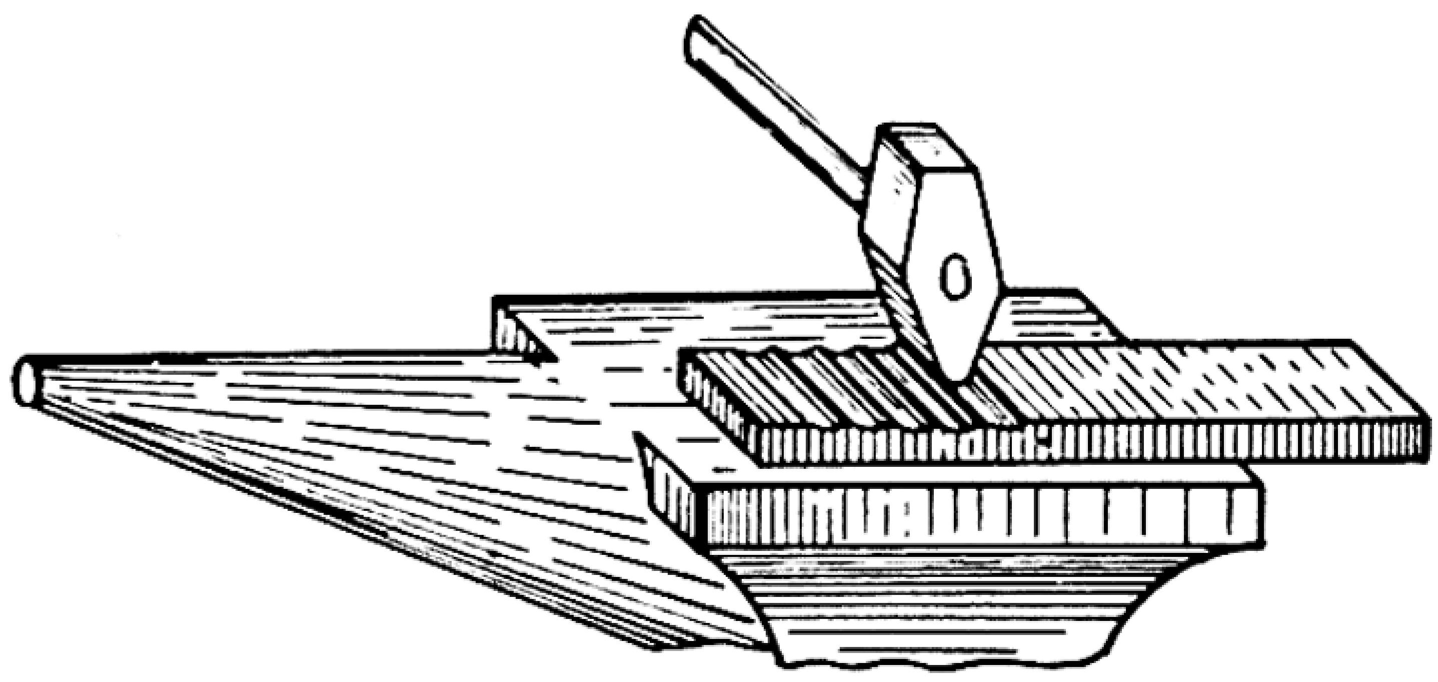


Fig. 75. Drawing-out a bar

Work must always be drawn out in a square section. If a round piece of stock is to be forged into a round bar of smaller diameter, it must be first forged down into a square bar, drawn out to a cross-section approaching the required final diameter and the square bar then forged into a hexagonal, and the hexagonal bar—into a round bar. If, however, an attempt is made to draw out round stock without these intermediate operations, the face of the sledge-hammer will strike only a small section of the metal, which will lengthen very slowly and, moreover, only on the surface; the inner layers of the metal will not be forged, and this circumstance may lead to the development of cracks in the forging.

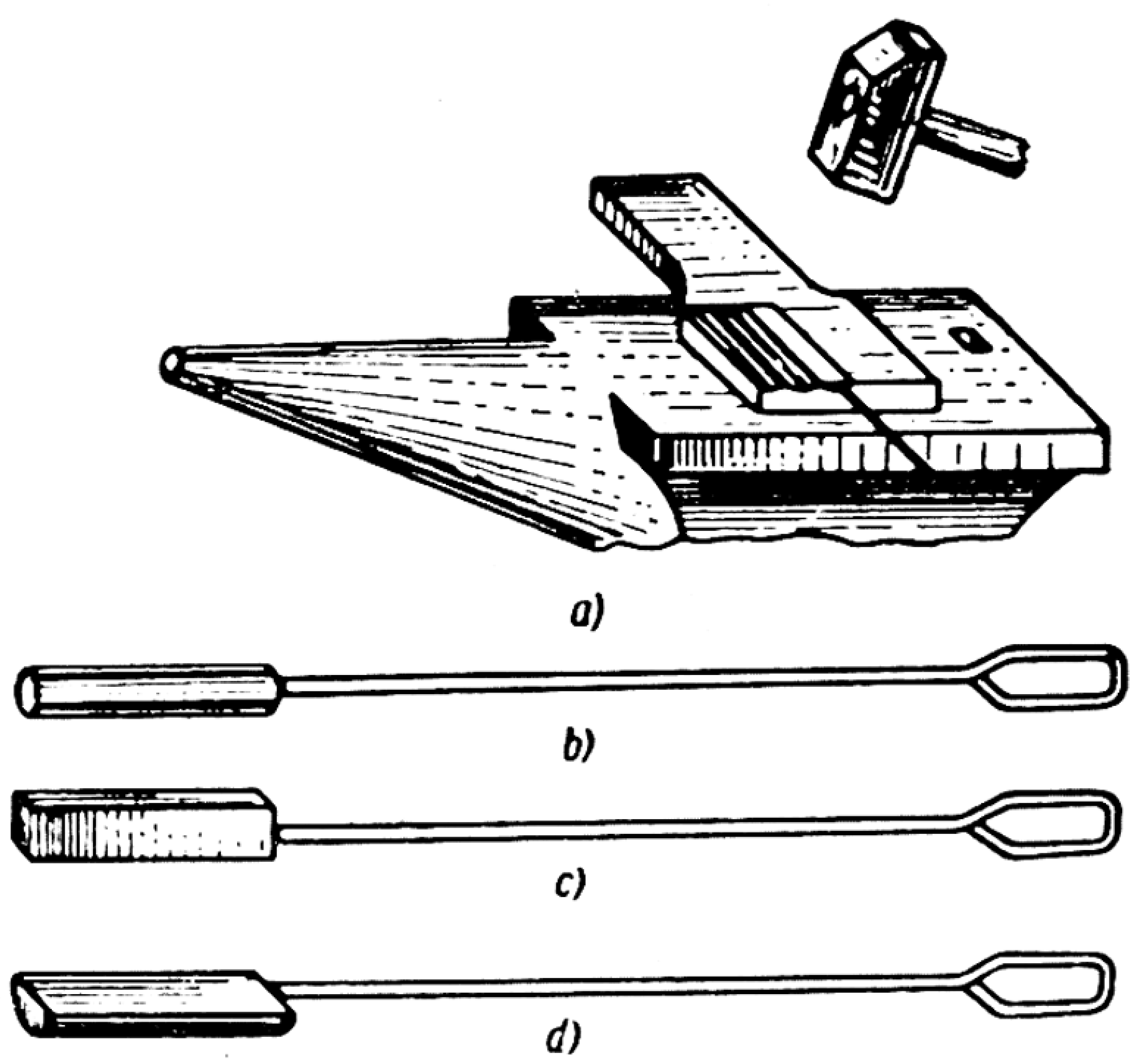


Fig. 76. Spreading a piece of stock:
a) scheme of drawing-out; b) round-faced fuller; c) flat-faced fuller; d) half-round faced fuller

Fullering, or spreading, is a forging operation whereby the width of a piece of work is increased to a greater extent than its length. Spreading must be commenced from the middle of the stock. A narrow steel bar called a spreader is placed in the middle of the stock (Fig. 76), and struck with the sledge-hammer; the force of the blow on the spreader is transferred to the metal over a small area, after which the spreader is shifted first to the right and then to the left,

each time being struck with the sledge-hammer. By thus moving the spreader from the middle of the work to its sides, the metal will be gradually spread from the centre to the side. After being spread out, the bar must be smoothed with a flat smoother (sometimes called a flatter) or with the broad face of the sledge-hammer.

In addition to ordinary blacksmith's tools, special tools are used for drawing-out and spreading metal. These tools include:

Spreaders are employed for drawing-out and spreading metals; they are made in a great variety of shapes (see Fig. 76). Flat faced fullers or spreaders are employed for smoothing-out the surface of the forging after it has been drawn out or spread.

Fullers are employed for drawing-out metal and also for finishing grooves and concave surfaces. Fullers are made of tool steel and hardened; their faces are polished. They are also made in a great variety of shapes. Fig. 77, *a* shows a round-headed fuller for making grooves and concave surfaces; the fuller shown in Fig. 77, *b* is used for drawing-out. The top illustration in Fig. 77 shows how a fuller is used for drawing-out a bar of steel.

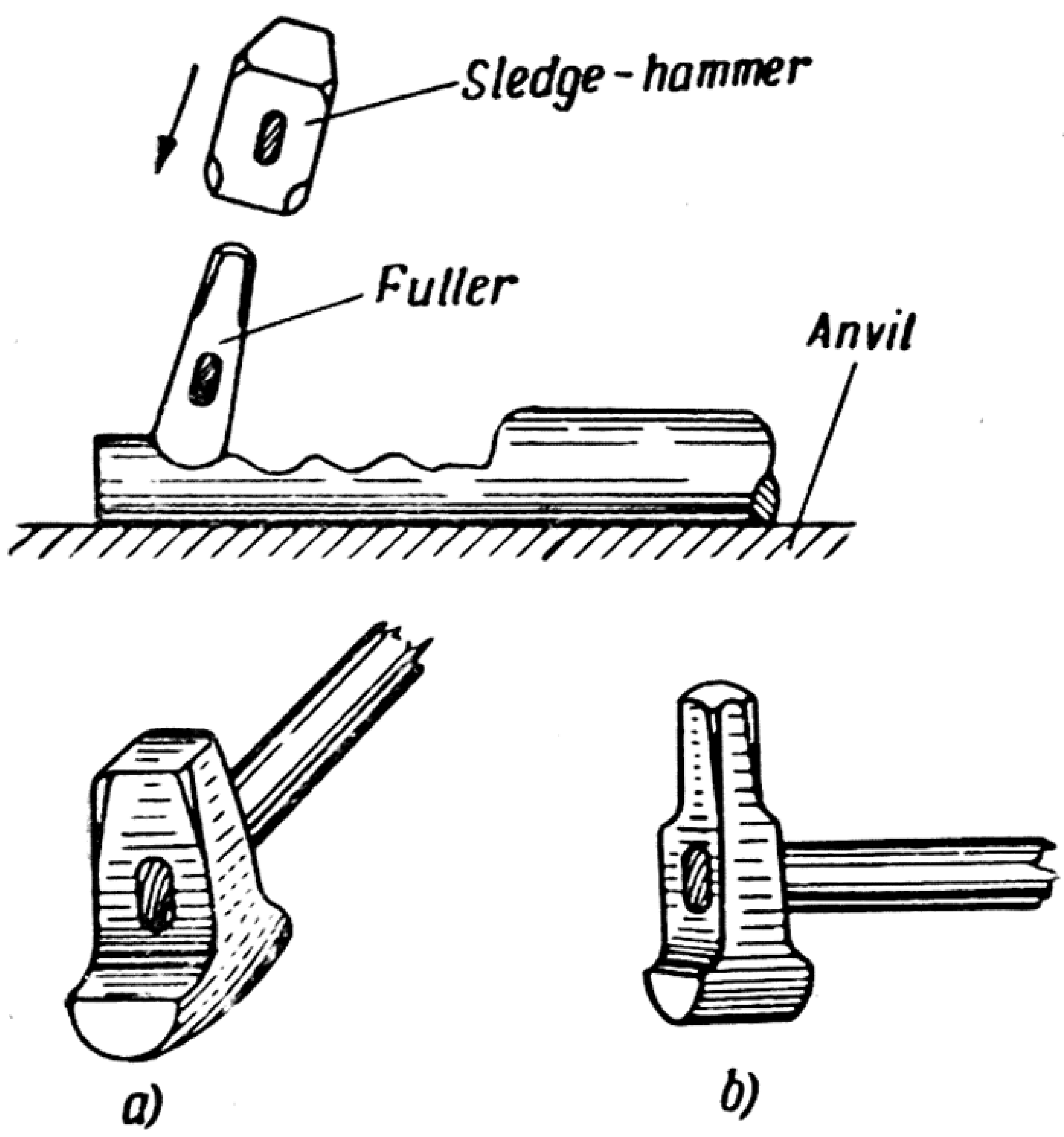


Fig. 77. Fullers:
a) sledge-hammer; b) fuller; c) anvil

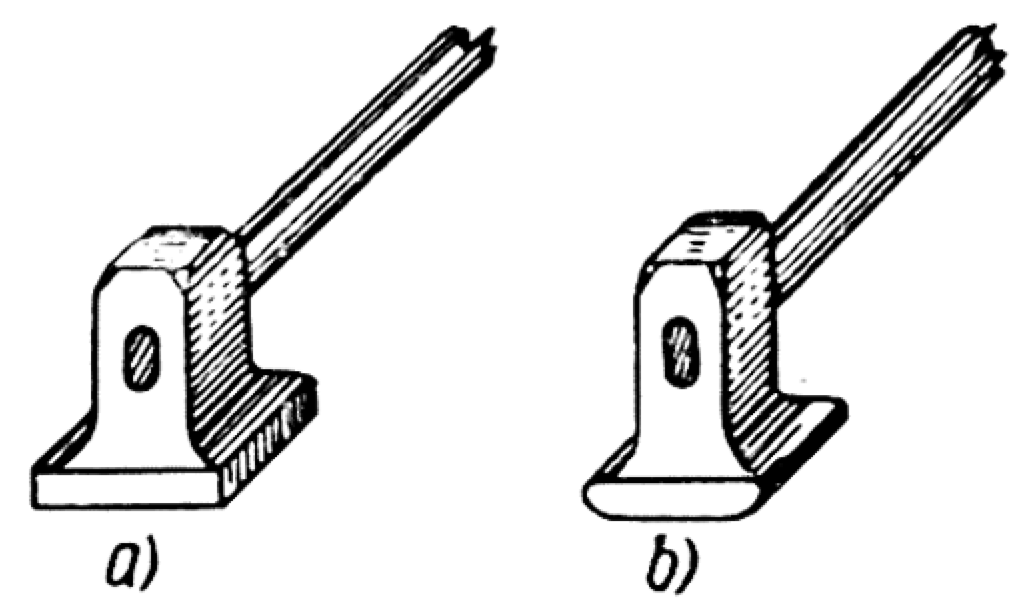


Fig. 78. Smoothers

Smoothers, or smoothing hammers, are employed for levelling and finishing flat surfaces. They are made with flat faces (Fig. 78, *a*) or with sharp or rounded edges, as in Fig. 78, *b*. As a rule, after a piece of work has been drawn out with a fuller, its surface is levelled with a smoother. When levelling a surface, the smoother should be struck lightly, as in this case no considerable deformation of the metal is necessary; it is only necessary to level the uneven surfaces and to bring the forging to the required dimensions.

Swages are employed for swaging (drawing-out) or changing the sectional shape of round work. Swages are usually made in pairs, or

sets—top and bottom swages. The bottom swage, or swage block, as it is sometimes called, is held by its shank in the hole of the anvil (Fig. 79, *a*). The top swage (Fig. 79, *b*) is fitted with a wooden handle, and is placed over the work; the striker hits the rop swage with his

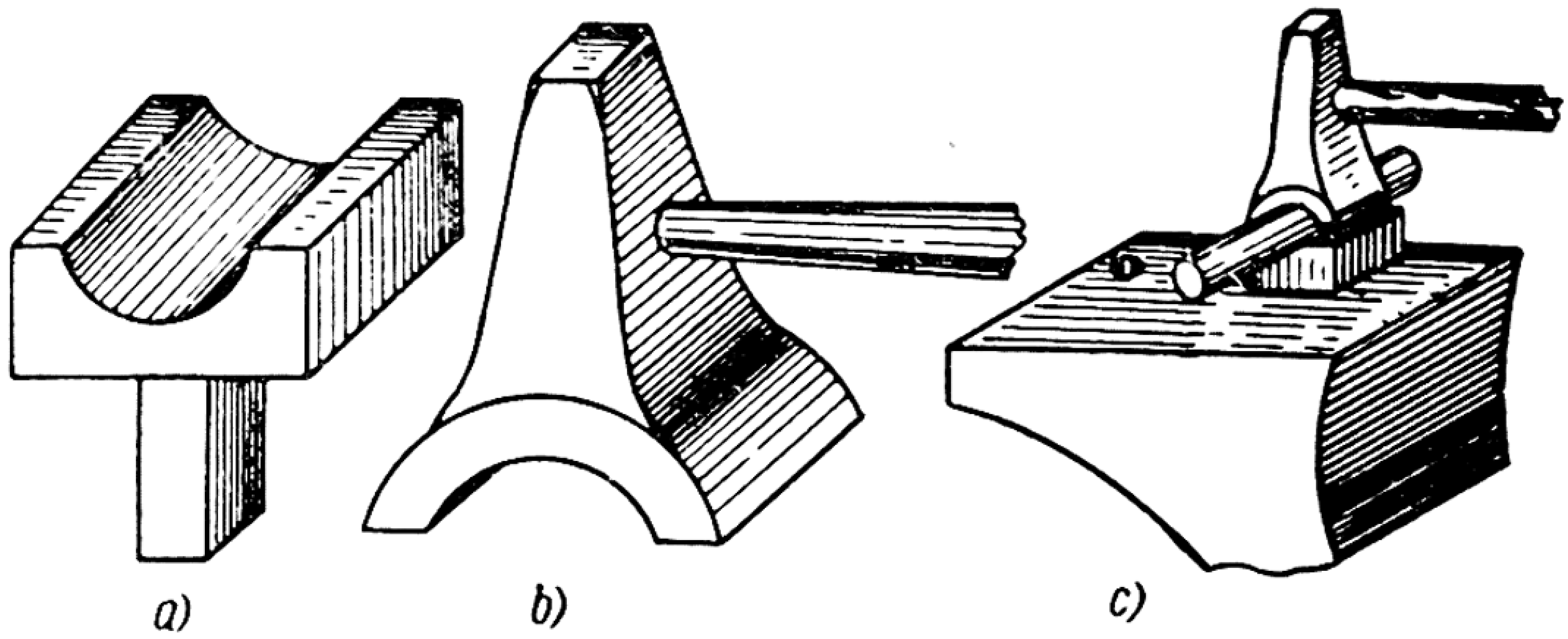


Fig. 79. Top and bottom swages

sledge-hammer. Fig. 79, *c* illustrates how a round piece of work is drawn out with the aid of top and bottom swages. In addition to round swages, blacksmiths use swages of other cross-sections as, for instance, hexagonal swages, used for finishing bolt heads, etc.

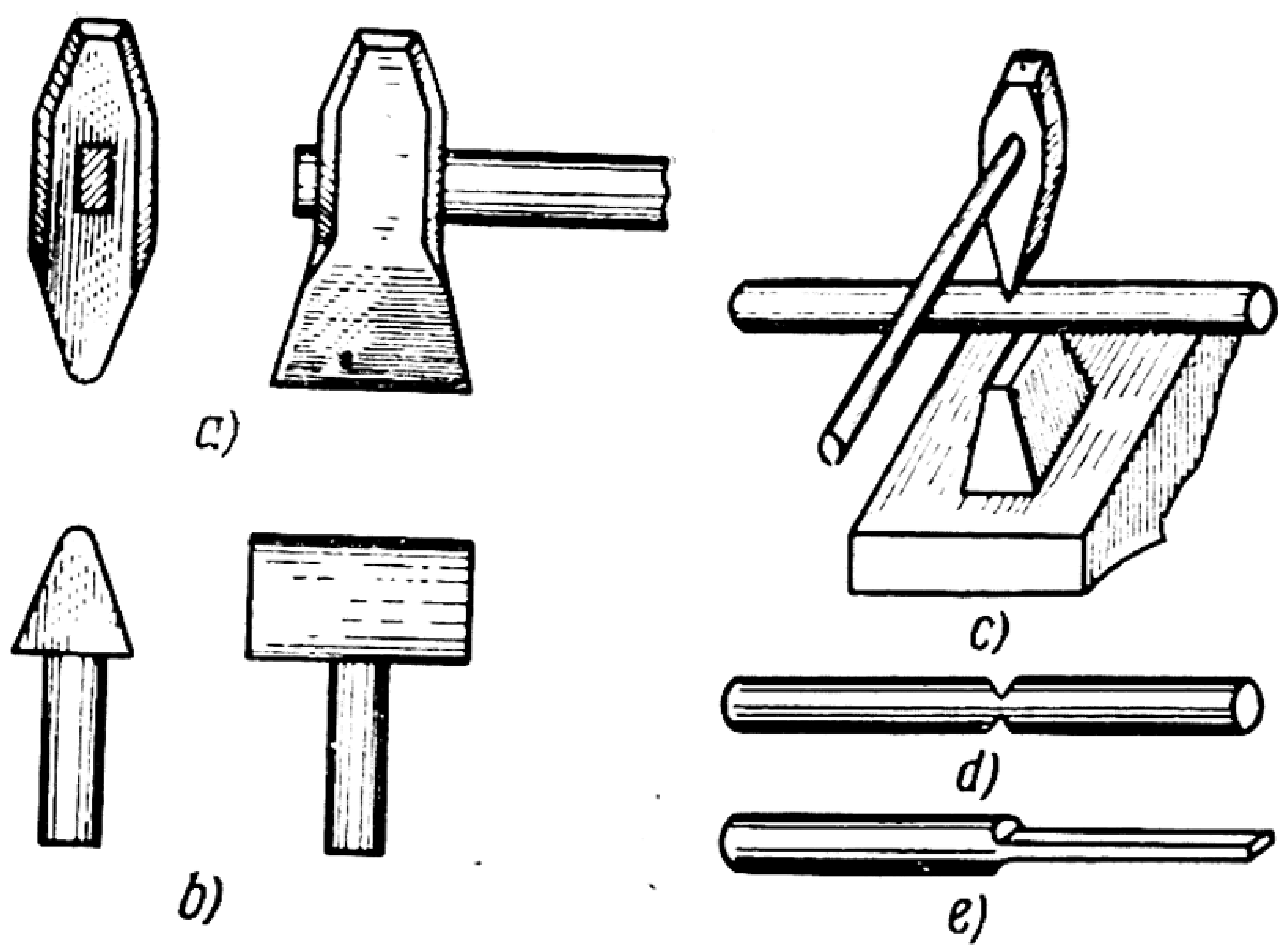


Fig. 80. Sets, or chisels

Hardies, *chisels*, or *hot sets*, as they are more often called, are tools used for nicking metals. Nicks are made in work to indicate where to begin reducing the cross-section of a piece of work, i. e., the commencement of the drawing-out operation. They are used in couples—the bottom set or anvil cutter, which has a shank for insertion into the hardie-hole of the anvil, and the top hot set, which has a handle

and is placed over the metal at the spot where the nick has to be made. Fig. 80, *a* shows a top hot set, and Fig. 80, *b*—an anvil cutter. Nicking is usually the first operation in forging. By driving the bottom and top sets into the work to the desired depth, as shown in Fig. 80, *c*, the blacksmith prepares the stock for the subsequent drawing-out operation. Fig. 80, *d* shows a piece of work nicked before being drawn out, while Fig. 80, *e* shows the same piece of work after being drawn out from one end.

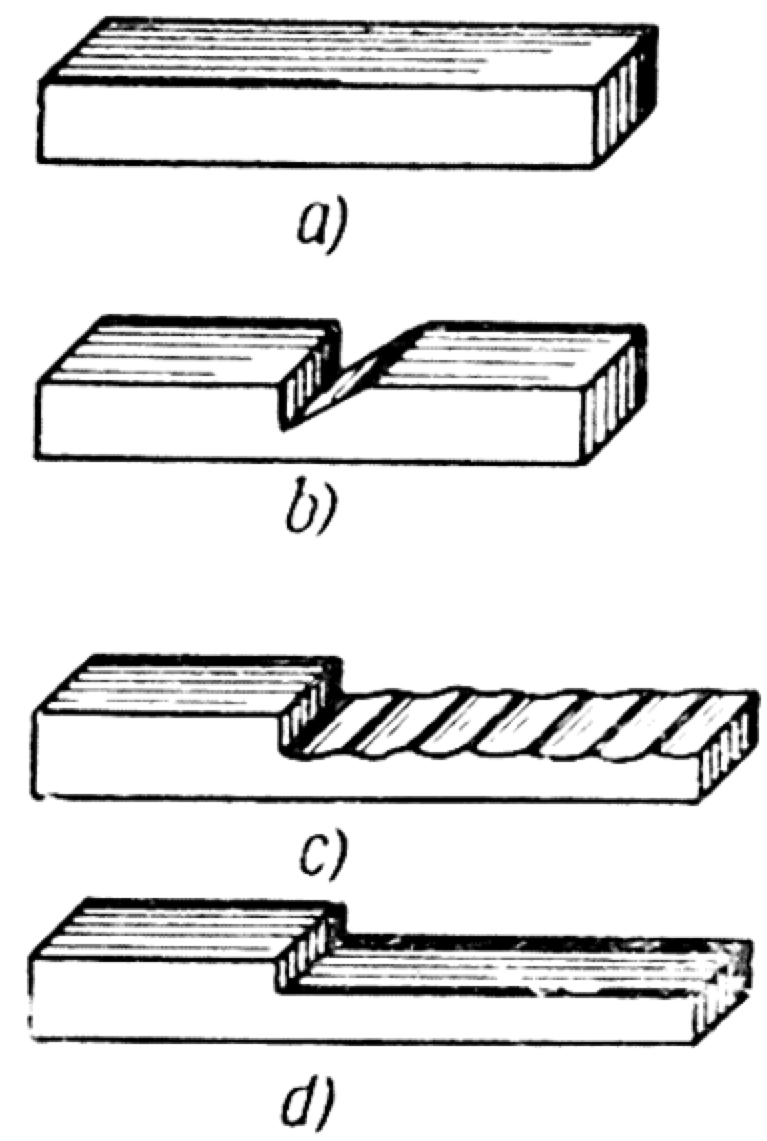


Fig. 81 Drawing-out a bar with a single shoulder

Below are given some *examples of drawing-out*, spreading and finishing the surface of a forging.

Example 1. It is necessary to draw out a square bar (Fig. 81, *a*) into a bar with one shoulder (Fig. 81, *d*). This work is performed by the following operations and with the following tools:

1. *Setting the stock.* In order to mark the place from which the stock has to be drawn out, it must be necked to a depth equal to the height of the shoulder, i. e., it must be set. The stock is heated in a hearth or small furnace to forging temperature (1,150-1,200°C) and removed with the aid of a pair of square jawed tongs; a ring is slipped over the tongs, and the stock is placed on the anvil. The distance from which the square bar is to be drawn out into a flat bar is measured off with a steel folding rule, or ruler. The blacksmith places his hot set on this spot, and the striker drives its edge into the metal to the required depth with light blows of his sledge-hammer. After necking, the stock will appear as shown in Fig. 81, *b*. If during the necking operation the temperature of the stock falls to 800° C, it must be reheated in the hearth.

2. *Drawing-out the stock.* The heated stock is then placed on the anvil, which must be previously wiped clear of scale. The blacksmith places his fuller on the part of the stock to be drawn out, and the striker hits the fuller with frequent, heavy blows. The blacksmith gradually shifts the fuller from the nick towards the end of the part to be drawn out.

To ensure a sound forging, the stock must be turned from time to time (after every 2 or 3 blows) on to its edge and lightly hammered in this position. When hammering thin work on its edges, care must be taken not to bend it. If it is bent, it must be immediately straightened out.

After the stock has been drawn out its shape will be as shown in Fig. 81, *c*, i. e., the surface of the drawn-out section will be uneven.

It must be smoothed out with the aid of a flat smoother (see Fig. 78, *a*), after which it will appear as shown in Fig. 81, *d*.

Example 2. It is required to draw out one end of a square bar (Fig. 82, *a*) into a flat bar of smaller cross-section as shown in Fig. 82, *d*.

This is performed by the following operations and with the following tools:

1. *Setting the stock from both sides.* The heated stock is placed over an anvil cutter inserted in the hardie-hole of the anvil. The blacksmith places the top set on the stock, and the striker hammers

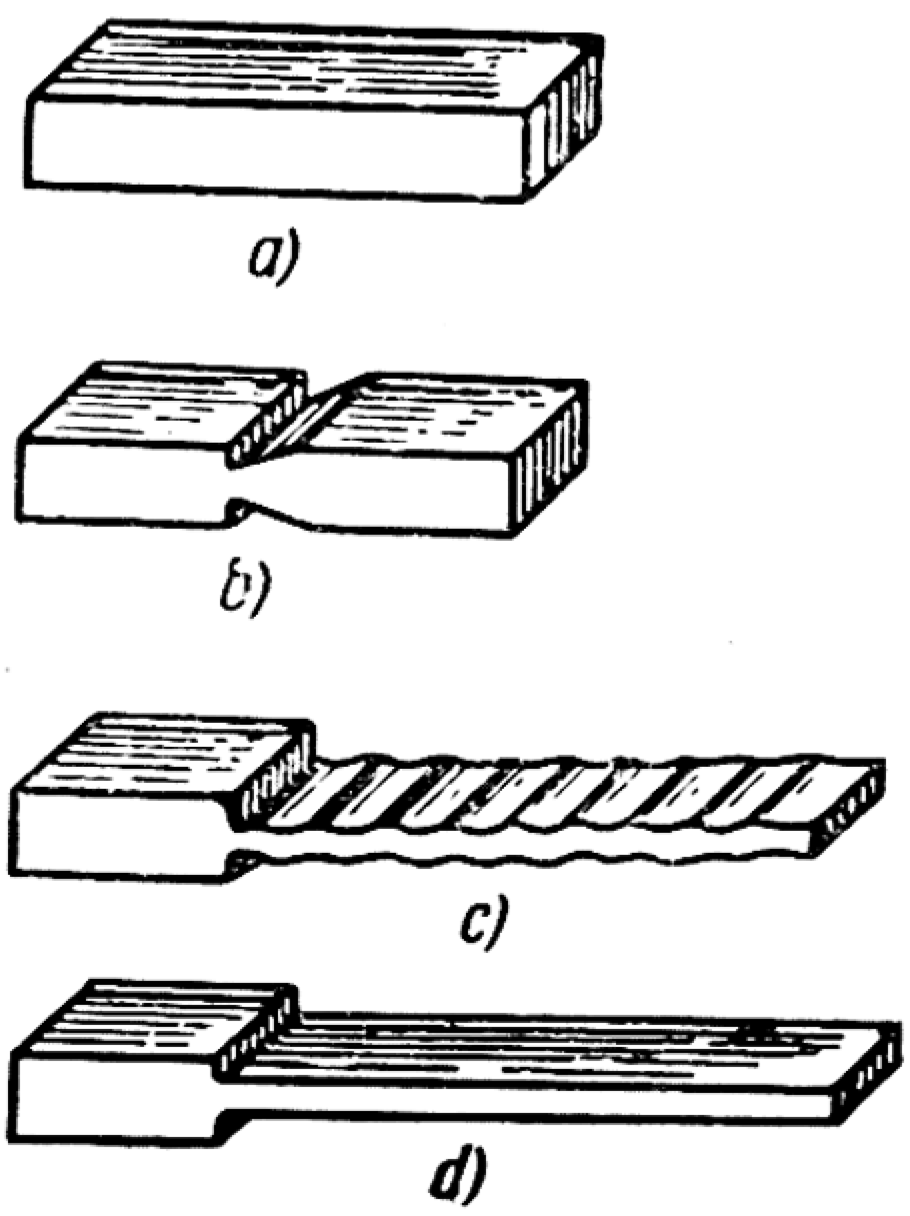


Fig. 82. Drawing-out a square bar from both sides into a flat bar with two shoulders

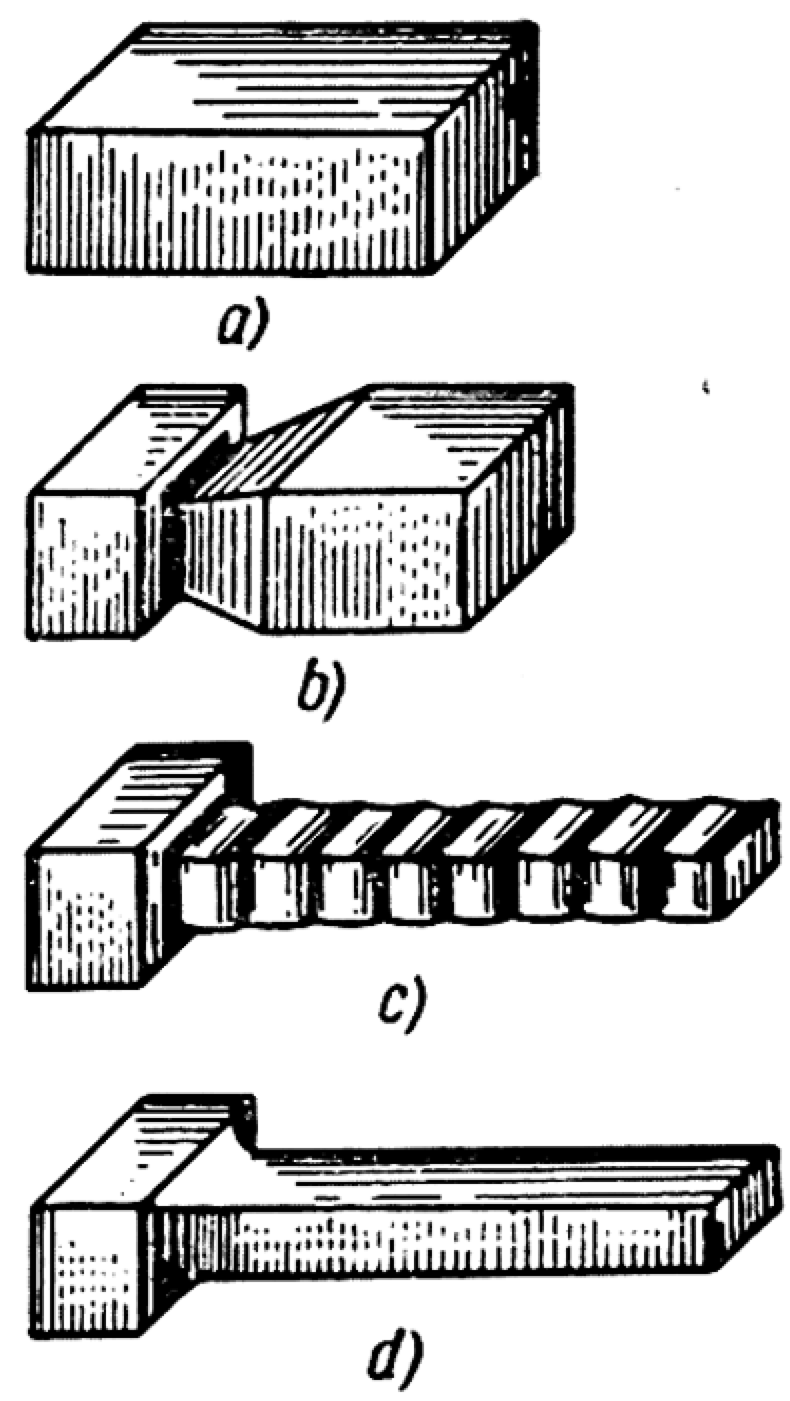


Fig. 83. Drawing-out a square bar into a square bar of smaller cross-section

it lightly with a sledge-hammer, thus forcing the anvil cutter and top set into the top and bottom of the stock to the required depth. After setting, the stock will appear as shown in Fig. 82, *b*. Care must be taken to place the hot set vertically on the stock and to see that it is exactly in line with the anvil cutter.

2. *Drawing-out the stock.* After setting, the stock is drawn out with the aid of the fullers, as described in the first example. In doing so, it must be drawn out with the fuller from one side, then turned through 180°, and drawn out from the opposite side. It must be turned through 90° aftdr every 2 or 3 blows, and its edge lightly hammered with the sledge-hammer. After being drawn out, the stock will appear as shown in Fig 82, *c*.

3. *Finishing the surface.* As in the first example, the drawn-out section of the work will have an uneven surface. To finish the surface, the forging must be heated, carefully cleaned of scale and smoothed

on all sides with a flat smoother (see Fig. 78, *a*), after which it will appear as illustrated in Fig. 82, *d*.

Example 3. It is required to draw out one end of a piece of stock to a square of smaller dimensions (Fig. 83, *a* and Fig 83, *d*). For this purpose it is necessary:

1. *To set the work from both sides.* As in Example 2 the stock is set on two opposite sides, then turned through 90° and the other two sides are set to the necessary depth of the shoulder; after this, the work will appear as illustrated in Fig. 83, *b*.

2. *Drawing-out the stock.* The stock must be drawn out with the aid of fullers. After each blow, the stock is turned through 90°. The stock will finally appear as illustrated in Fig. 83, *c*.

3. *Finishing the surface.* The forging (Fig. 83, *c*) must be heated, carefully cleaned of scale, and levelled with a flat smoother. After every 2 or 3 blows the forging is turned through 90°. After surface finishing, the forging will appear as illustrated in Fig. 83, *d*.

Example 4. Drawing a square bar into a round bar. A square piece of stock must never be directly forged to a round bar of considerable smaller diameter (i. e., entailing considerable reduction of cross-section) as this may result in cracks. The bar must be first drawn down to a bar of smaller cross-section, with opposite sides equal to or slightly less than the required diameter of the round bar.

1. *Drawing the stock into a square bar of smaller dimensions.* The operations and tools are the same as those employed in the third example. After drawing-out, the work will appear as illustrated in Fig. 84, *a*.

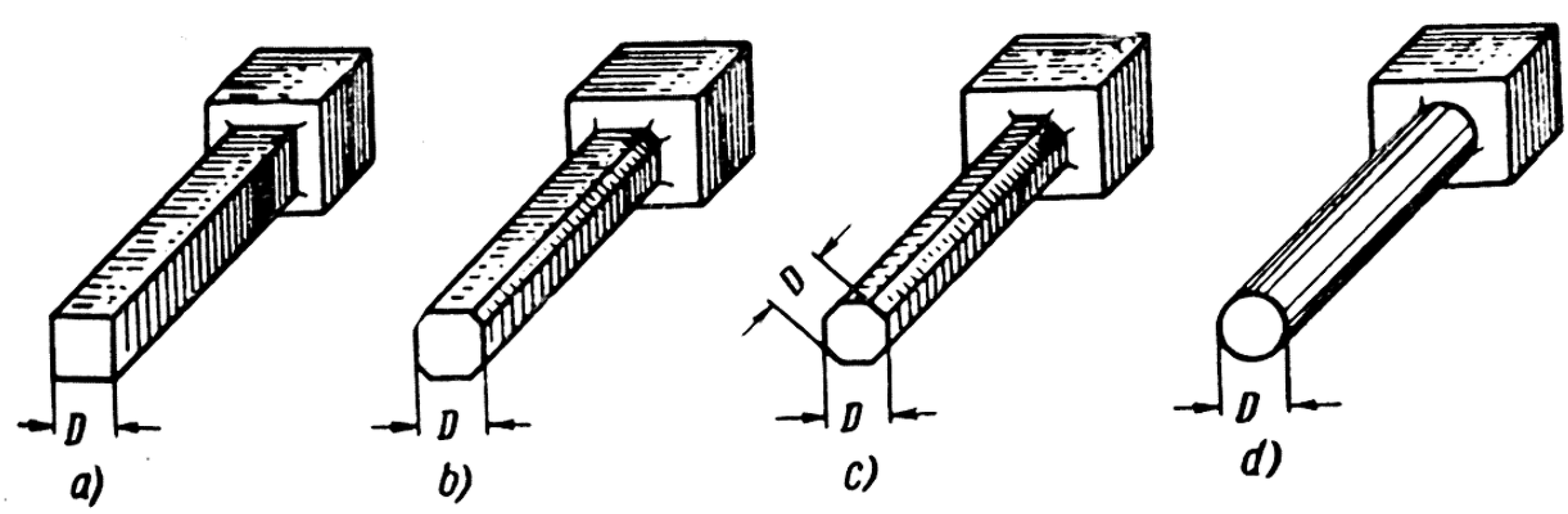


Fig. 84. Drawing-out a square bar into a bar of round cross-section

2. *Forging the square bar to an octagonal cross-section bar.* After heating the work and cleaning it from scale, the blacksmith rounds its corners by placing it with the aid of his tongs on its edge on the anvil, when the striker rounds the edges with frequent, heavy blows of his sledge-hammer. The stock must be turned through 90° after every 2 or 3 blows, so that the edges are rounded off gradually on all

four sides. After such hammering, when all its edges have been rounded off, the forging will appear as illustrated in Fig. 84, *b*. After being hammered to an octagonal cross-section, it will have the shape shown in Fig. 84, *c*.

Forging. Hammering (rounding) the octagonal bar into a round bar. Before proceeding with this operation, the work must be heated, cleaned from scale and then placed on the bottom swage (see Fig. 79, *a*), which is inserted in the hardie-hole of the anvil; the blacksmith then places the top swage (see Fig. 79, *b*) over the work, and the striker hits the former lightly with his sledge-hammer (see Fig. 79, *c*).

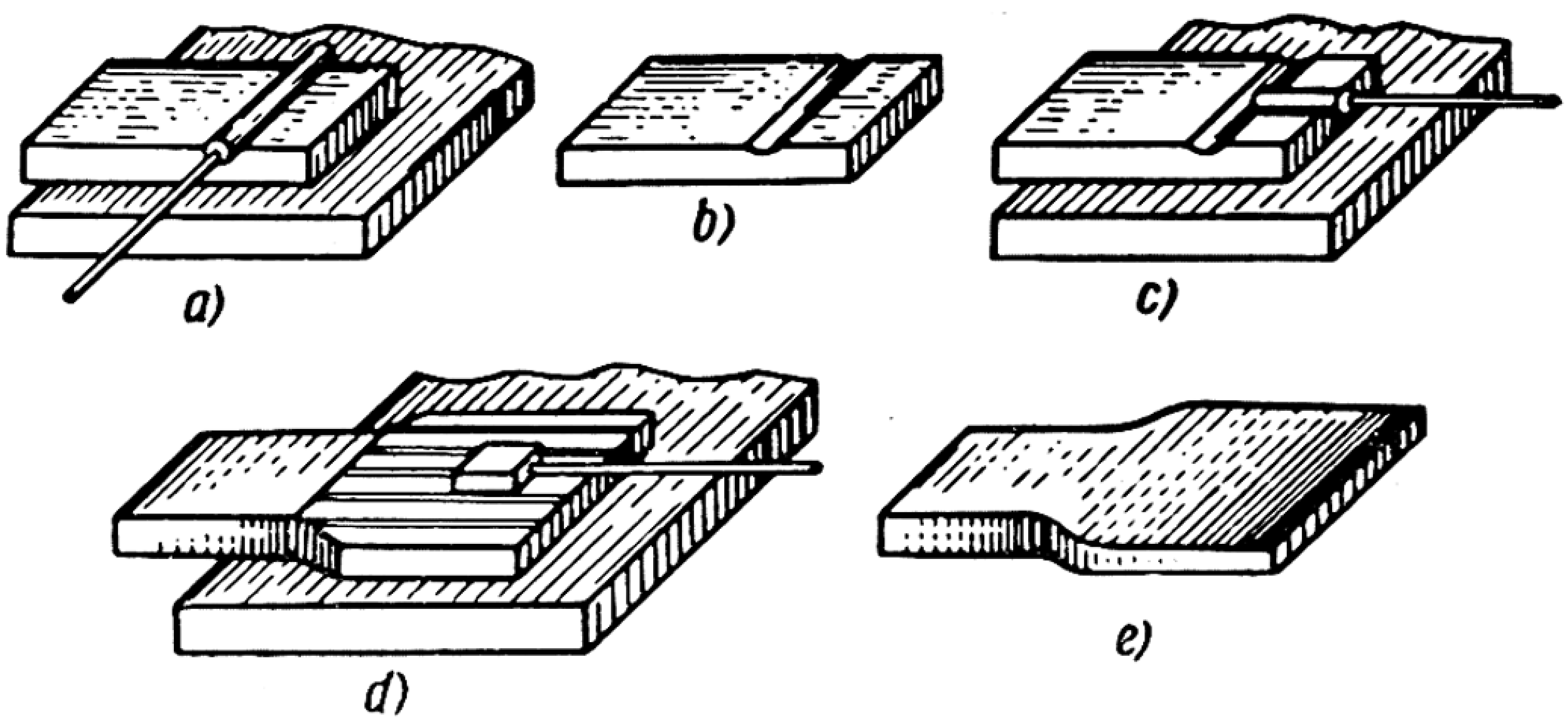


Fig. 85. Spreading a bar

During this operation the blacksmith must turn the work around its axis and gradually move it forward until it is forged completely to the required cross-section. After forging the work will appear as illustrated in Fig. 84, *d*.

Example 5. Spreading a bar. To do this the following operations are performed:

1. *Setting the stock*. The heated stock is placed on the anvil and the amount to be spread measured off with a folding ruler or steel rule. A thin round spreader is then placed across the bar (see Fig. 85, *a*). The striker then forces the spreader into the metal to the required depth with his sledge-hammer. The bar will then look as illustrated in Fig. 85, *b*.

2. *Spreading the bar*. The spreader is placed in the middle of the bar and is struck lightly with a sledge-hammer (Fig. 85, *c*).

The spreader should be moved uniformly along the bar, alternately to the left and right. After spreading, the bar will appear as illustrated in Fig. 85, *d*.

3. *Levelling the rough surface of the stock*. After the work has been spread, its surface will be rough and uneven. To level the irregularities of the surface, the work is heated, cleaned, placed on the anvil,

and then finished with a flat smoother (see Fig. 85, *d*). After smoothing the spreaded work will appear as illustrated in Fig. 85, *e*.

Defects During Drawing-out and Spreading. The following defects may occur during drawing-out and spreading:

1. The stock *may sag* if it has been hammered on one side only without being turned (Fig. 86). Moreover, it may bend because of not having been heated uniformly throughout its entire cross-section. To prevent work from bending when being drawn out, it should be thoroughly heated throughout its entire cross-section to the forging temperature. During the drawing-out operation it must be turned through 180° after every 2 or 3 blows.

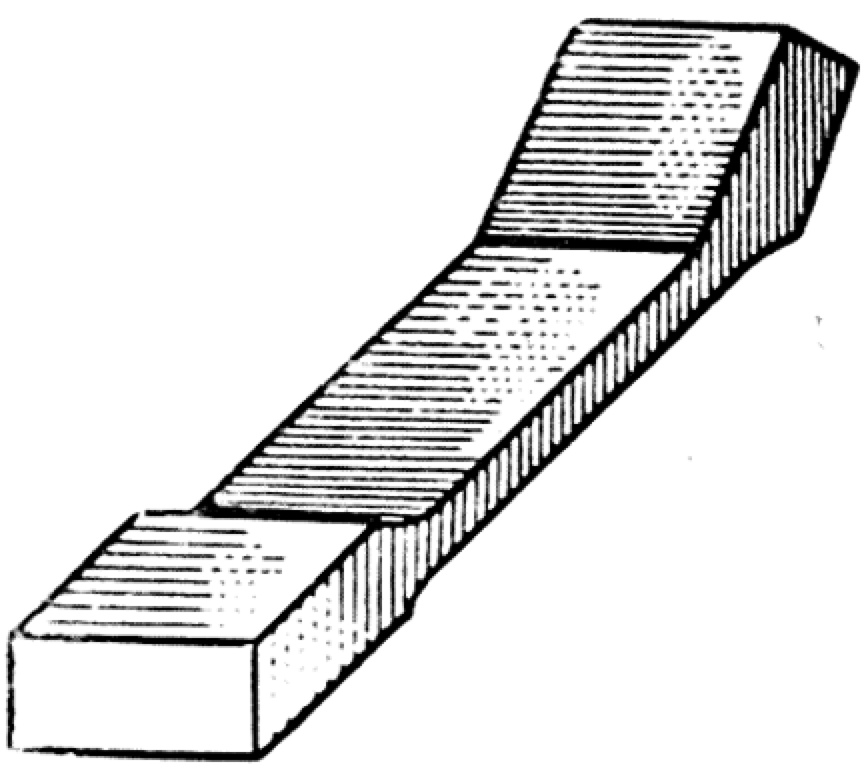


Fig. 86. A piece of work bent during forging

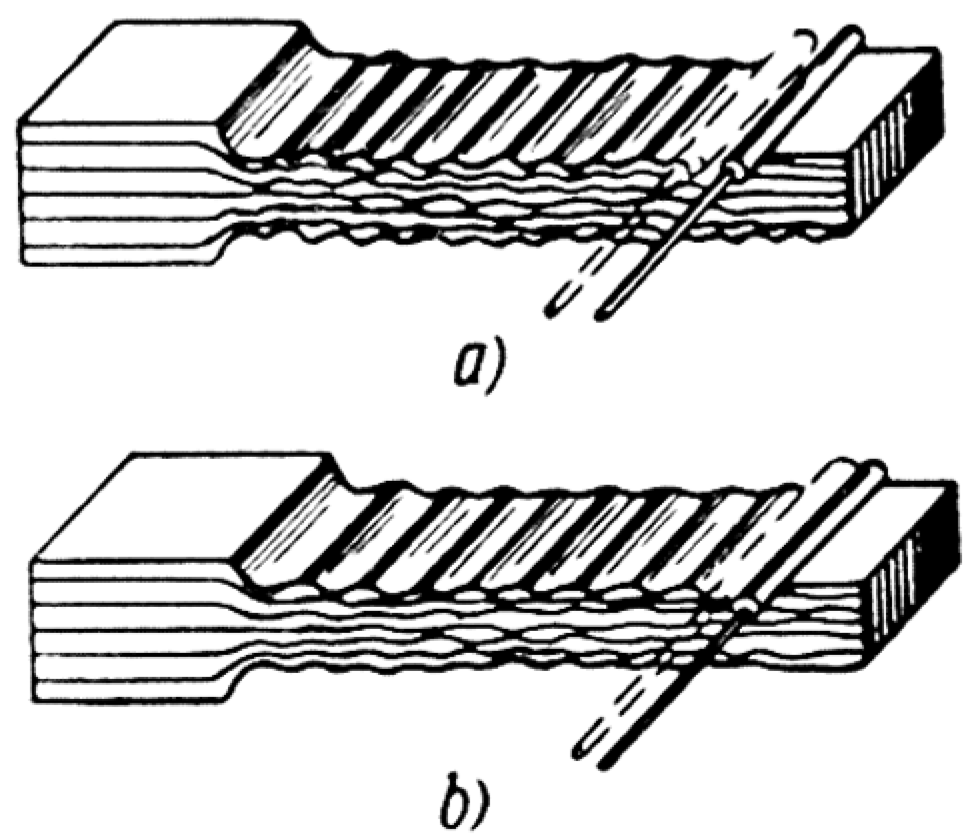


Fig. 87. The fibre of metal during drawing-out

2. If the work is being drawn out with the aid of fullers and spreaders, and deep nicks are made in it, there is a *danger of cutting the fibre* of the steel and thus lowering its mechanical properties. To avoid this, the fuller or spreader must be shifted along the work so that the place where one blow was struck is overlapped by the following blow. After such a thorough drawing-out or spreading, the surface of the forging will be smoother and its fibres will not be cut.

Fig. 87, *a* illustrates how a spreader should *not* be shifted along the length of a piece of stock; the hammer blows were too heavy, the hollows too deep, and the fibre of the work has been cut through. Fig. 87, *b* shows the right way of shifting a spreader.

3. *Laps* occur when a tool is improperly placed on the stock. Fig. 88, *a* illustrates how a smoother should *not* be placed on the work when levelling it; Fig. 88, *b* shows a forging with a lap.

4. If a round or square piece of stock is drawn out into a round bar of smaller diameter without the intermediate forging steps previously described, the metal will *not be uniformly* forged throughout its cross-section: only its surface layers will be lengthened, and this may result in *axial cracks*. Fig. 89 illustrates cracks and folds resulting

from improperly forging (drawing-out) a round bar to a bar of smaller diameter; the hammer blows were too light in this case.

5. Forging metal at low temperatures (below the required temperature) results in what is known as *cold-working* of the metal, i. e., increased hardness and brittleness of the surface metal. Continued hammering of cold metal can result in surface and even in internal cracks; cold-working is a defect which can be remedied, but in most

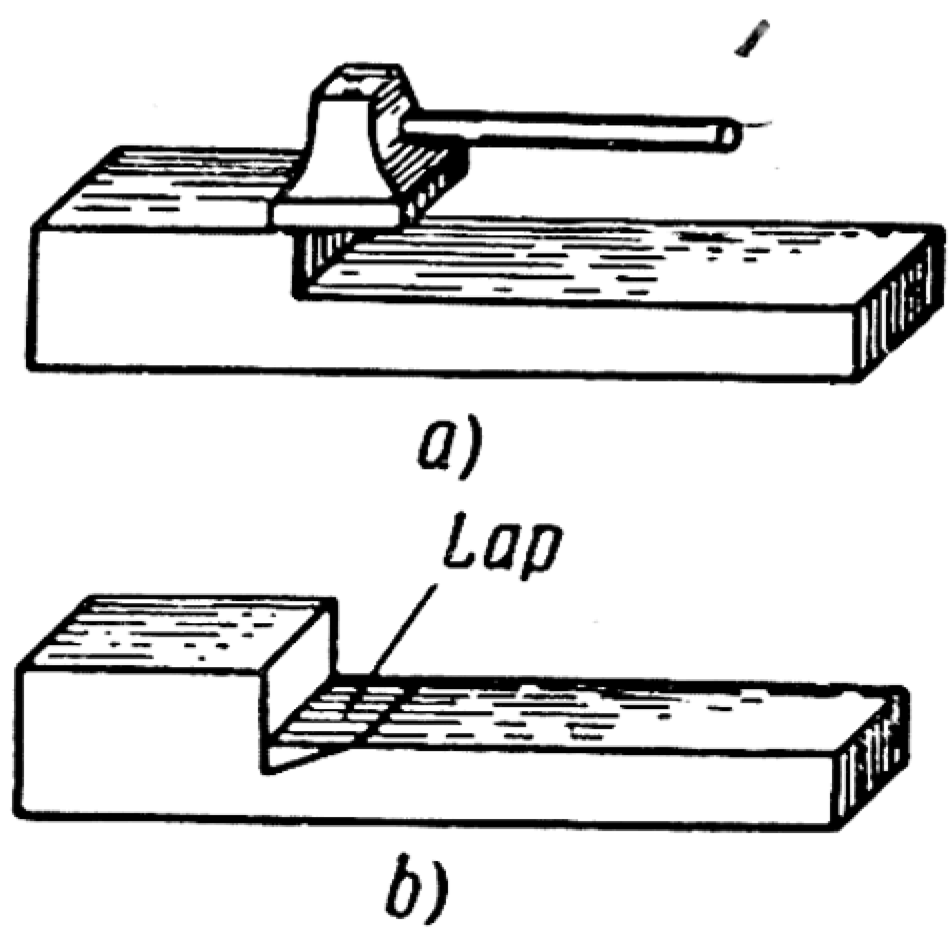


Fig. 88. Formation of a lap in a piece of stock

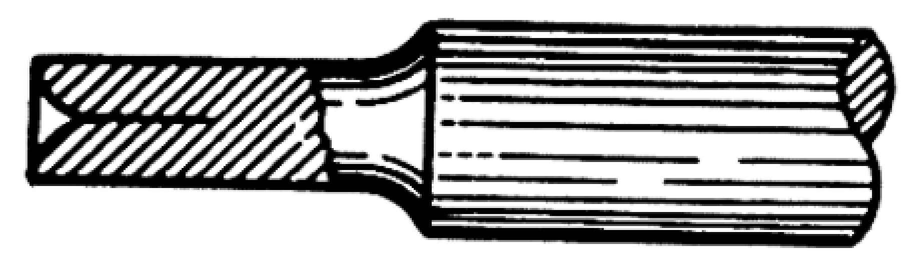


Fig. 89. Formation of cracks and folds during forging

cases cracks cannot be remedied, and such forgings have to be rejected. Forgings are generally annealed to eliminate the effects of cold-working.

To avoid cold-working and cracking when drawing-out work, particularly in the case of bars of light sections, they should be drawn out rapidly by a sledge-hammer, with frequent, heavy blows, and the work turned through an angle of 90° after every 2 or 3 blows. Never draw out work which has become cold during forging, but always reheat it to the required forging temperature.

CHISELLING

Chiselling is an operation whereby a part of metal is separated from a piece of stock or from a forging. Cracks and other surface defects can be removed from a forging or a piece of stock by chiselling. Two types of chiselling processes are employed in hand forging, notching and cutting-off.

Notching is a form of chiselling whereby the work is nicked, or notched, to a definite depth. Notching is employed for making necks or shoulders in a piece of work. This operation is also called marking or setting. Some examples of setting, or notching, when drawing-out bars with one shoulder (i. e., from one side), with two shoulders (i. e., from opposite sides) and from all four sides, were described earlier.

Blacksmiths should always remember never to set a piece of work too near its end, as, during the subsequent drawing-out operations,

axial cracks and folds may appear on the end of the forging, which will have to be scrapped.

Fig. 90 gives an example of the formation of *folds* and *axial cracks* on a forging caused by setting too near the end of the stock.

Cutting-off is a form of chiselling whereby a long piece of stock is cut into several specified lengths, or a forging is separated (cut off) from its stock. Metals can be cut either hot or cold. It is dangerous to chisel cold steel, as chips of metal are liable to fly off in various directions for considerable distances, and to injure workers. For this reason all recommended safety precautions must be taken when cold chiselling; and, above all, working places should be protected by wire netting and workers kept away from the end of the work being cut.

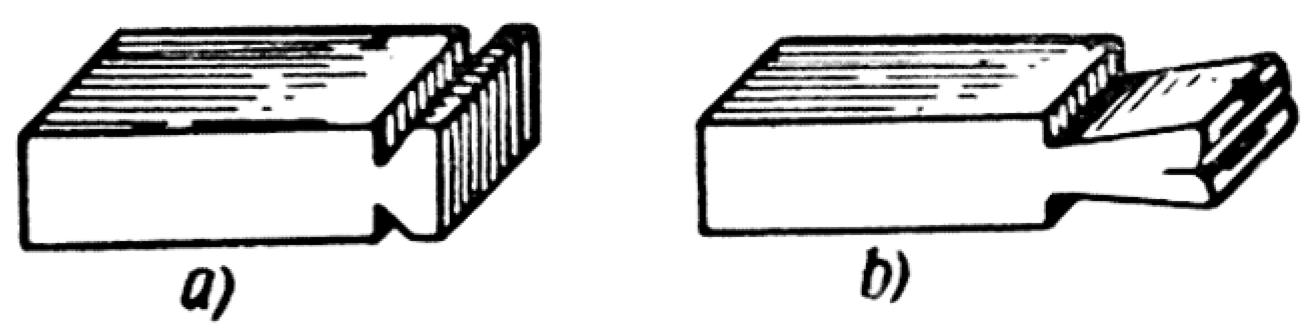


Fig. 90. Formation of axial cracks and folds

Cutting thick or wide cold bars is a long operation. Moreover it entails frequent grindings of the set. During chiselling considerable stresses and even cracks may occur in the metal. For this reason only thin and narrow mild steel bars are chiselled in the cold state. Special and high-alloy steels should never be chiselled cold, as considerable stresses occur at the ends of the cold stock in the spots where it is being cut; these stresses give rise to cracks.

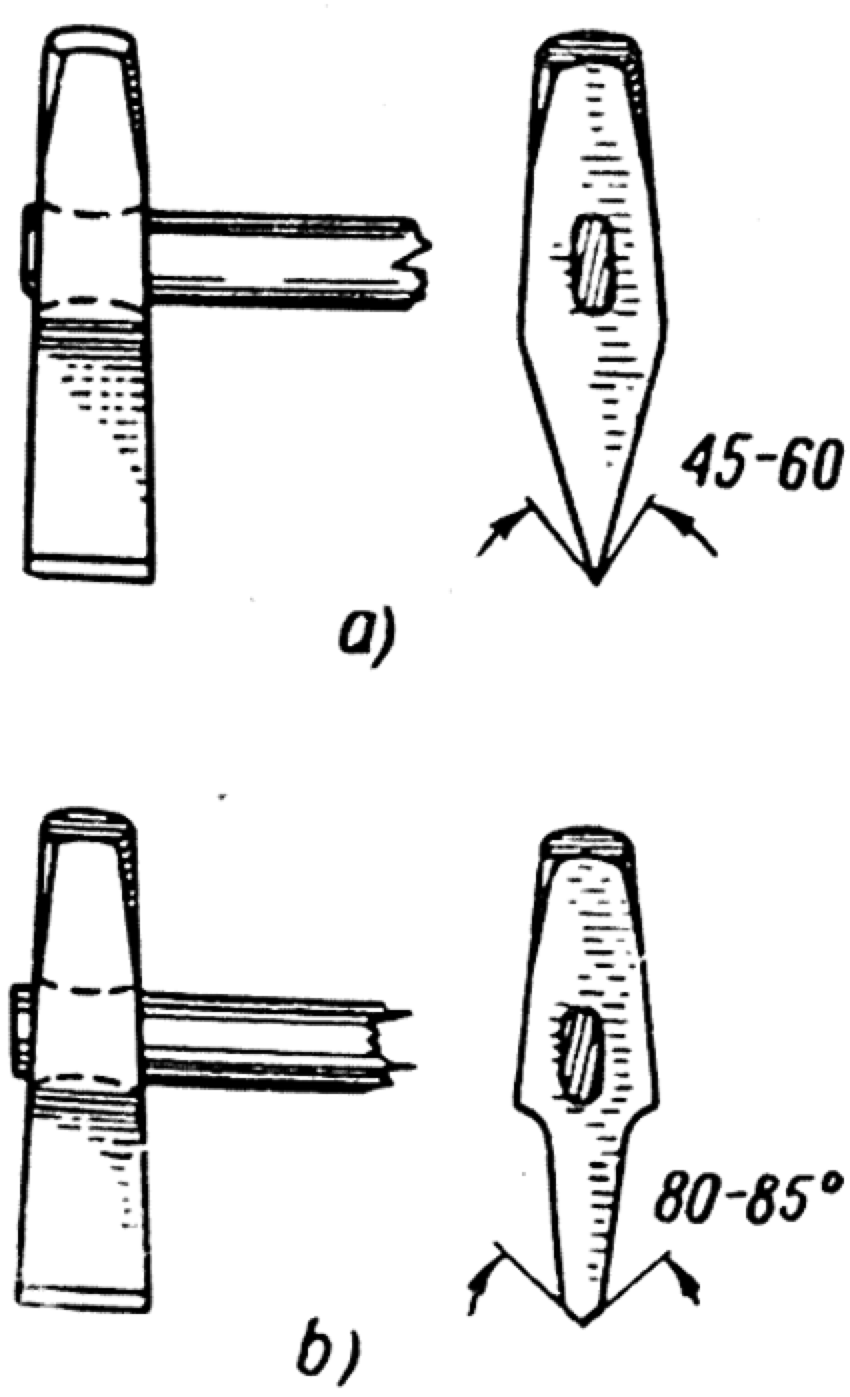


Fig. 91. Blacksmith's sets, or chisels

For hot chiselling, steel must be heated in a blacksmith's hearth or furnace to a light cherry-red heat, i. e., to 850-950° C.

Blacksmith's *chisels*, or sets, as they are sometimes called, are used for cutting steel. They are made in various designs according to whether they are used for chiselling cold or hot metal. Chisels for cutting cold metals must be ground to an angle of 45-60°, while those for cutting hot metals must be ground to an angle of 80-85°.

Fig. 91, *a* shows a *cold set* used for *cutting cold metal*, while Fig. 91, *b* shows a *hot set* for *cutting hot metal*. These chisels are made of hard tool steel; after forging, the cutting edge (lip) of the chisel must be ground to the proper angle and hardened. The chisel head is either

fitted on a wooden handle, or a handle made by twisting steel wire. When cutting hot steel, the lip (cutting edge) of the chisel must be frequently cooled in cold water as otherwise it will become very hot and consequently will rapidly become soft and useless. The cutting edge of a cold set should be greased with machine oil to increase its life.

When cutting with chisels, the hammer blows are directed onto the chisel head, which must be slightly rounded. Frequently an anvil cutter is used to lighten cutting operations (Fig. 92).

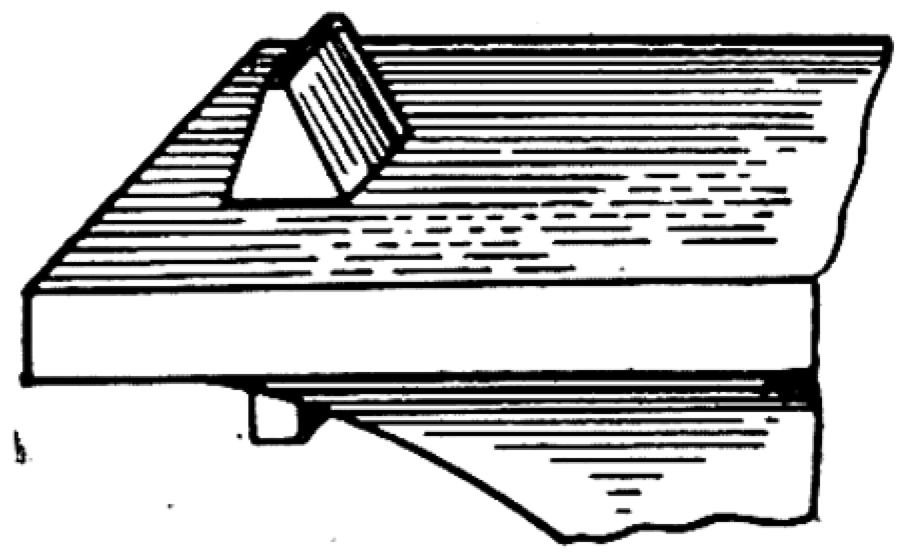
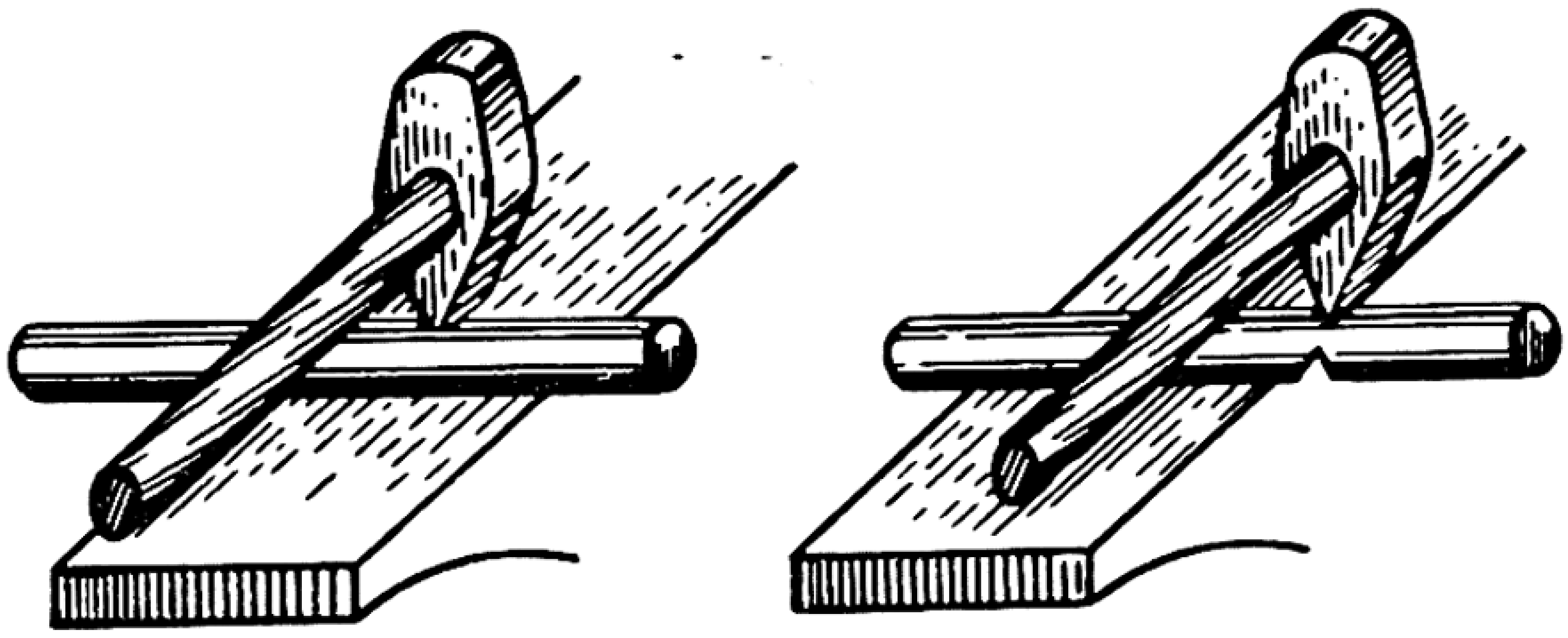


Fig. 92. Anvil cutter

Anvil cutters are made with square tails, or shanks, for inserting in the anvil hardie-hole. The head of the anvil cutter is ground, like that of a chisel, to an angle which depends upon the operation to be performed (either hot or cold cutting). The anvil cutter is first inserted in the hardie-hole and the work is then placed on its edge; the hot (or cold) set, depending on the kind of operation, is placed over the blade of the anvil cutter and struck with the sledge-hammer. The use of anvil cutters considerably speeds up cutting operations.

Anvil cutters are made of hard tool steel; their cutting edges are tempered after hardening.



a) b)

Fig. 93. Cold cutting a bar

Examples and Methods of Cutting Work. Before cutting a cold piece of stock the blacksmith marks the place, where the stock is to be cut, with chalk. He then places the stock on the anvil, holding it in place with his left hand and places the chisel on the spot where the stock is to be cut (Fig. 93, *a*). The striker hits the chisel with his sledge-hammer to make a notch about one half the thickness or diameter of the stock.

Care must be taken to keep the work steady on the anvil, and the chisel—perfectly vertical on the work, or otherwise, when struck with the sledge-hammer, the chisel may fly aside and injure anyone in the vicinity.

After the spot where the stock is to be cut off has been notched, the work must be turned through an angle of 180° and the chisel placed exactly opposite the notch; the required length of metal can then be cut off by giving the chisel a few blows with the sledge-hammer. Before striking the last blow, the blacksmith must place the stock on the anvil so that its cut-off end is parallel with the edge of the anvil, as shown in Fig. 93, *b*.

If the steel is very hard, four notches will be required instead of two, i. e., the stock will have to be turned through 90° after each blow, instead of 180°. When cutting thin sheet steel the surface of the anvil should be protected with a plate of mild steel in order to avoid blunting the edge of the chisel on the hardened surface of the anvil.

Special and alloy steels, as well as thick steel plates (over 20 mm in thickness) and engineering steel stock, are cut hot. The work is first heated in a hearth or furnace until it is light cherry-red (850-950°C); the blacksmith then grips it with his tongs and places it on the anvil, where he notches the place at which the work is to be cut off. He then places it on the anvil cutter, and puts the hot set on the work in a vertical position opposite the anvil cutter. The striker hits the chisel several times so as to leave a small neck between the set and the anvil cutter. During the cutting operation the blacksmith must take care to keep the hot set exactly over anvil cutter.

After this the work must be placed on the anvil with its notch over the anvil edge, the set inserted into the notch and the stock cut off with a light blow on the chisel.

Safety Rules for Chiselling. In addition to the ordinary safety precautions, the following rules must be observed during chiselling operations:

1. The head of the chisel should never be allowed to spread. When struck, such a head is liable to crack and split, chips may fly off and injure workers near by.
2. Blacksmiths and their helpers, when cutting metal with sets, must always stand so as not to be struck by chips of metal.
3. When cutting hot or cold metal, the last blow must always be made very carefully.
4. When cutting, care should be taken never to stand opposite the metal being cut, as pieces of metal may fly off and cause injuries. To prevent accidents during cutting operations, a movable guard should always be placed near the side of the anvil from which pieces of metal are liable to fly off.

5. Chisels should always be placed absolutely vertically on the work; when using an anvil cutter the chisel should be placed exactly opposite it; otherwise, on being struck, the chisel will fly aside and may cause injuries.

UPSETTING

Upsetting is a forging operation whereby the length of a piece of metal is reduced and its cross-sectional area is increased. *Three types* of upsetting are applied in forging practice: full, head and central upsetting. Sometimes the two latter types are called heading.

Full, or *complete*, *upsetting* is employed when it is necessary to increase the cross-section of the stock along its entire length. For this purpose, the stock must be first heated and then placed upright on the anvil; its top end is then struck with a sledge-hammer, causing it to become shorter in length, but to increase in cross-section.

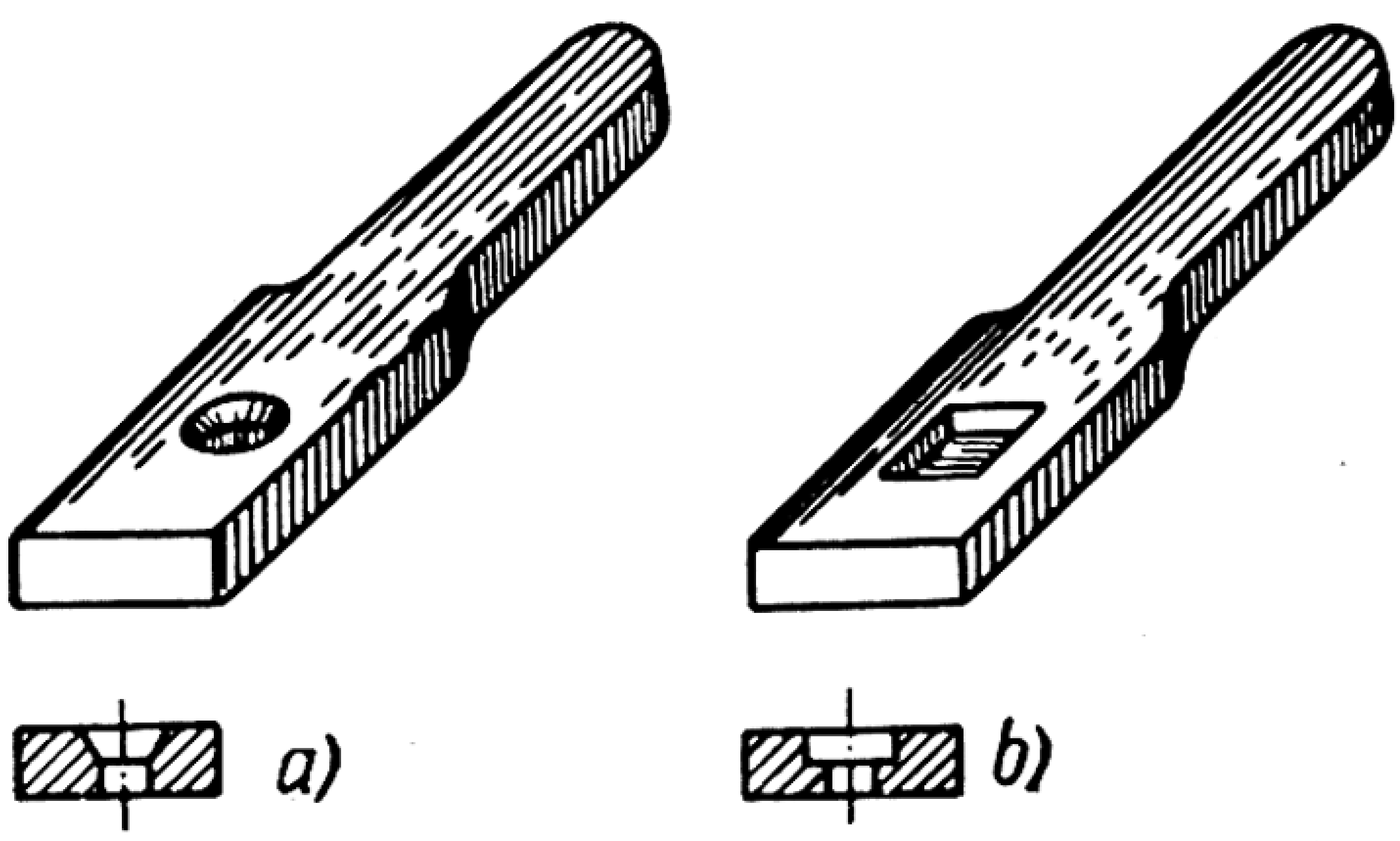


Fig. 94. Die header

Head upsetting is employed in cases when it is required to increase the cross-section of the stock; for *central upsetting*, only the central section of the stock is heated; the stock is then placed vertically on the anvil, and its head is struck with a sledge-hammer, thus increasing, or upsetting, the cross-sectional area of the centre of the stock. When it is required to upset only a small section of a piece of stock, and a considerable length of the stock has been heated, the excess length of heated stock which is not to be upset should be cooled by water.

When upset, the stock bulges out and assumes the shape of a barrel. Therefore the fibre of an upset piece of work or stock will be bent. If a very hard steel is heavily upset, the fibre may split, thus leading to the development of cracks. To ensure a perfectly homogeneous structure of the metal throughout its cross-section after upsetting, the fibre of the stock must run parallel to the direction of the hammer blows.

Soft metals upset more easily than hard metals; and the thicker the stock, the greater the energy required to upset it.

The usual blacksmith's tools are employed for upsetting: anvil, tongs, hand- and sledge-hammers. In addition, various other implements are employed depending on the work to be upset. Fig. 94, *a*

illustrates a *die header* for upsetting the head of a countersunk screw; Fig. 94, *b* illustrates a die header for upsetting a square bolt head; Fig. 95 shows a swage employed for straightening and finishing the hexagonal head of a bolt after it has been upset in a die header.

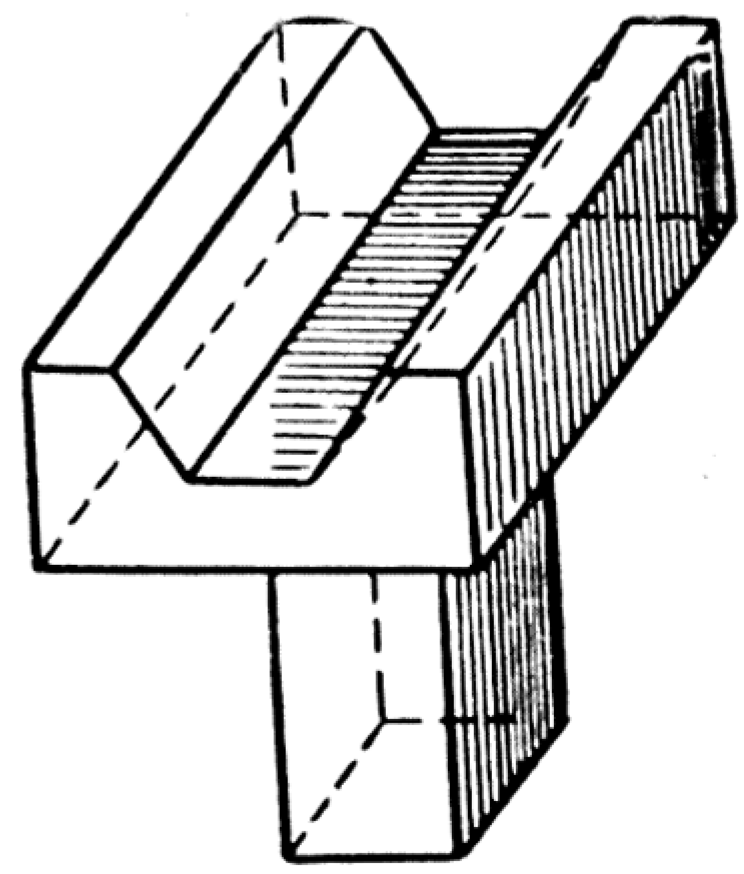


Fig. 95. Bottom swage

Before upsetting, the work must be heated thoroughly and uniformly through its entire cross-section and along the entire length to be upset; the temperature of the steel, which must be high, will depend on its grade, and will be specified by the shop foreman or technologist. To ensure uniform upsetting, the work must be rotated round its axis all the time it is being struck.

The length of the upset section of the work should not be more than 2-$2^1/_2$ times its diameter, or side of square, as otherwise it will buckle during upsetting. For instance, if the diameter of a piece of stock is 25 mm, the maximum length which can be upset

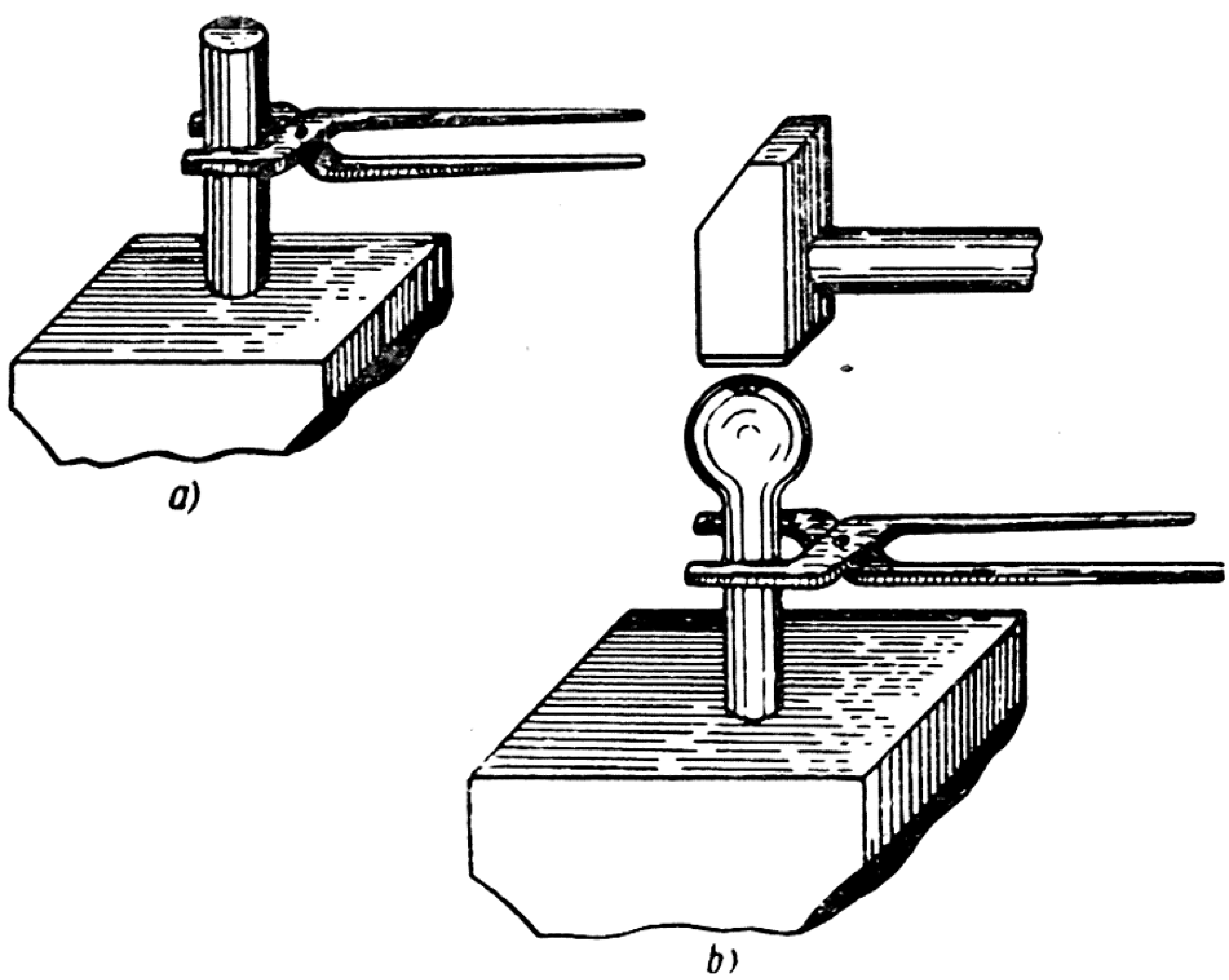


Fig. 96. Upsetting the end of a piece of stock

will be $25\times2.5=62.5$ mm. If the length of the section to be upset is 150 mm, the stock will buckle during upsetting.

Some examples of upsetting.

Example 1. Upsetting the end of a piece of stock. Heat the end to be upset in a hearth up to its forging temperature, and then

place the stock, hot end up, on the anvil. The blacksmith with his left hand supports the work in the tongs and, with the hand hammer in his right hand, shows the striker where to hit the work with the sledge-hammer. If the work is placed hot end down on the anvil, the length of the upset head will be greater, but its diameter will be smaller.

Fig. 96, *a* shows how a piece of stock is placed on an anvil for upsetting, and Fig. 96, *b* illustrates the upsetting of one end of the stock.

Example 2. Upsetting the central section of a piece of stock. The central section of the stock is heated in a hearth up to forging temperature. Then it is placed vertically on the anvil and gripped with the

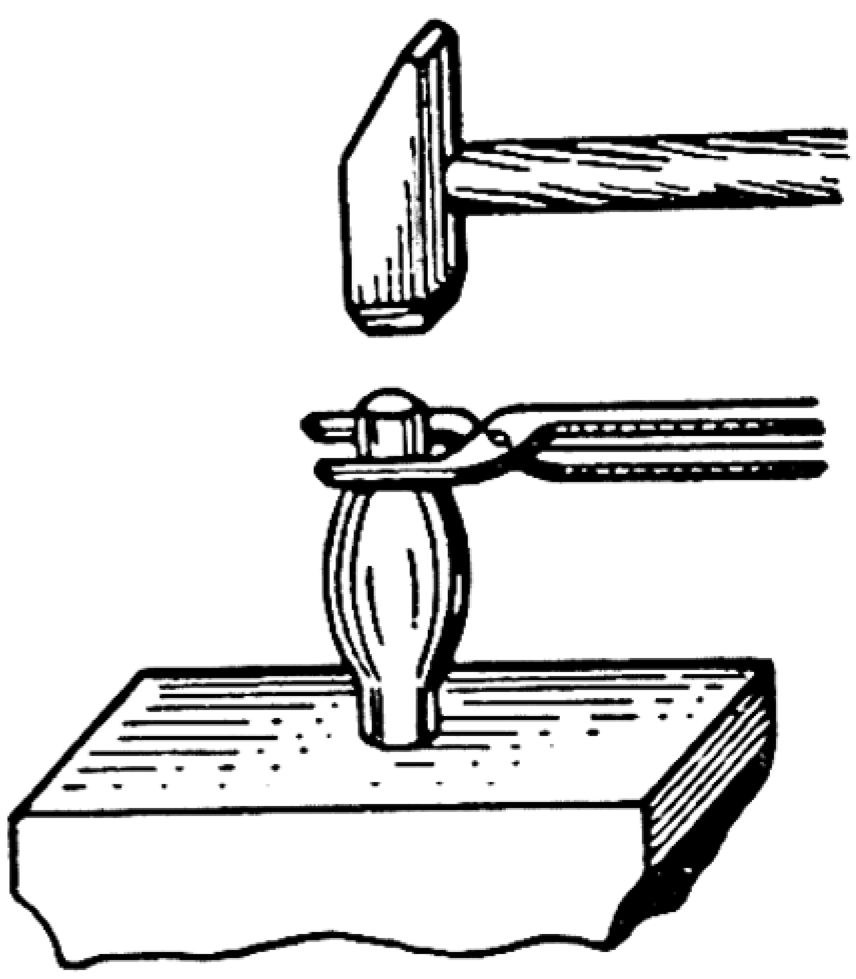


Fig. 97. Upsetting

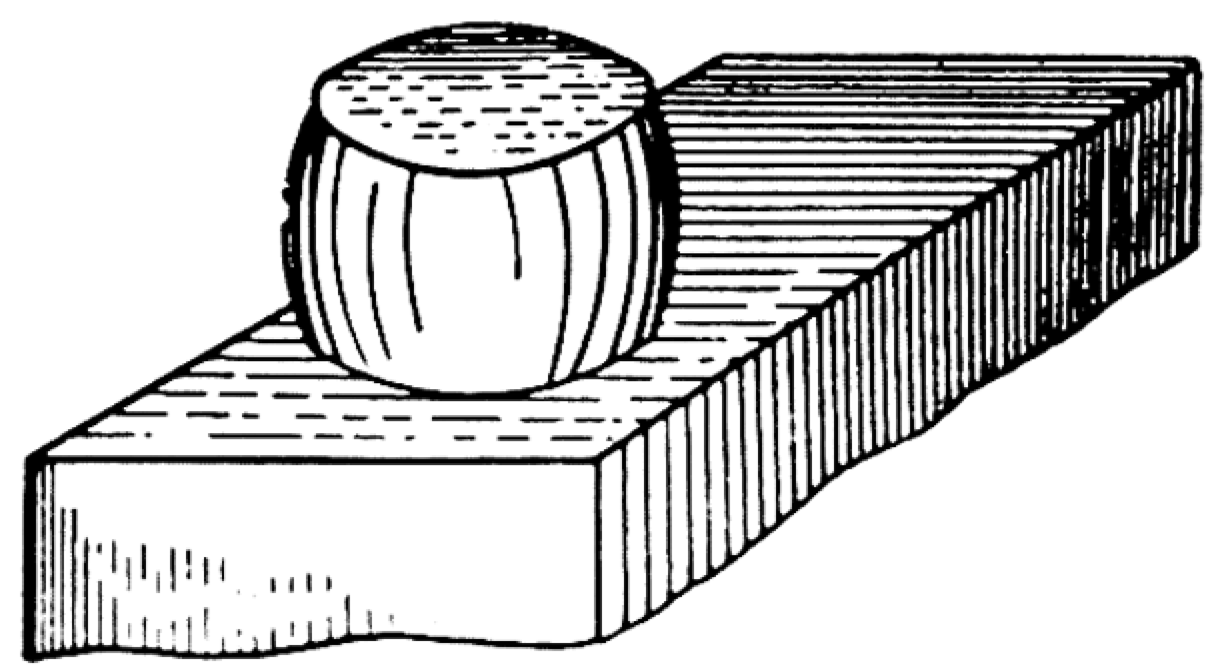


Fig. 98. Piece of stock fully upset

tongs, not at the point to be upset. The top of the stock is then struck with a sledge-hammer or hand hammer, thus upsetting the central portion. Fig. 97 illustrates the operation of upsetting the central portion of a piece of work.

Example 3. Complete upsetting of a piece of stock. The stock must be first heated uniformly along its entire length and then placed vertically on the anvil, being held in place by tongs gripping its centre. Then the top of the stock is struck, at first lightly and then more heavily. As the upsetting proceeds, the blows should increase in force and frequency.

Fig. 98 illustrates a piece of work after it has been upset. When upsetting work, care must be taken to prevent it from buckling or from becoming out of square.

Upsetting Defects. Upsetting defects include: 1) buckling of the stock during the upsetting process (Fig. 99, *a*), 2) the faces of the stock becoming out of square (Fig. 99, *b*).

The stock is liable to buckle and become out of square if:

1) The length of the stock exceeds 2-$2^1/_2$ times its diameter;
2) The stock is not turned round its axis during upsetting;

3) The stock is struck at the edges instead of in the centre of its end;
4) The stock is insufficiently heated throughout its cross-section;
5) The upsetting is continued without straightening the stock after it has begun to buckle.

In addition to these defects, folds are liable to occur in work being upset; they often appear after straightening a considerably bent piece of work (Fig. 100).

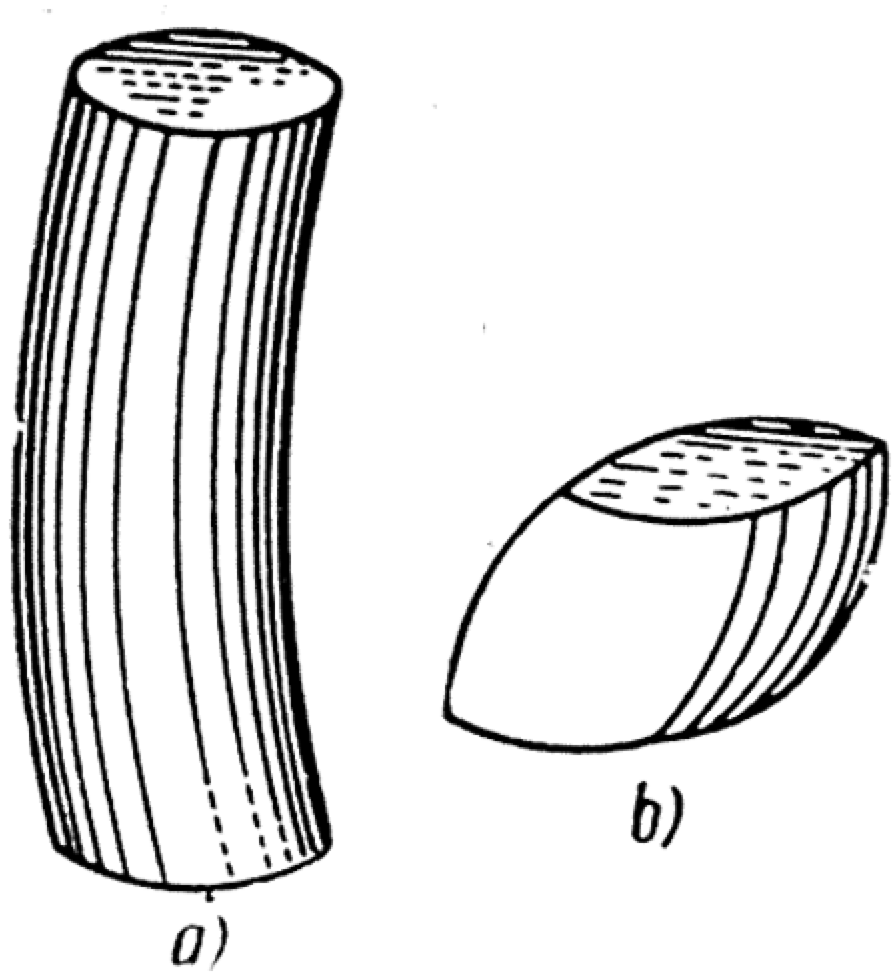


Fig. 99. Work buckled (a) and mis-shapen (b) during upsetting

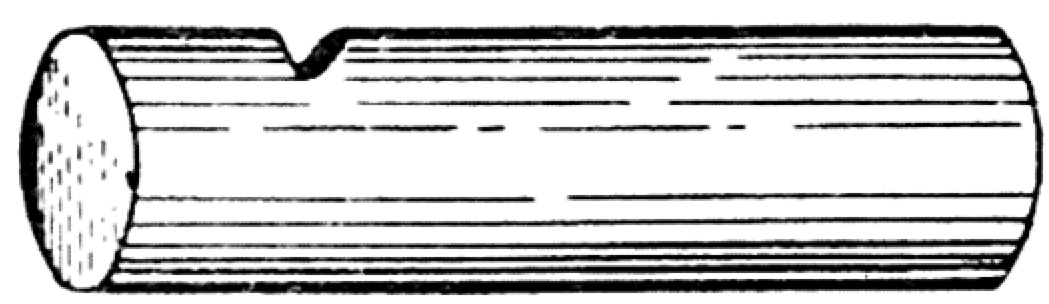


Fig. 100. Fold in stock

Surface and internal cracks are also liable to occur if the work has not been heated to the proper temperature, or if it has not been heated uniformly throughout its entire cross-section.

BENDING

Forging often entails bending a hammered stock or piece of work. The simplest method of bending a piece of metal in hand forging is to place it on the anvil and, holding it in place with one sledge-hammer, to strike its free end with a second sledge-hammer. If the forge shop is equipped with forging hammers, the stock can be secured between the top and bottom dies, and bent by striking its free end with a sledge-hammer. When a piece of metal is bent, its outer layers are

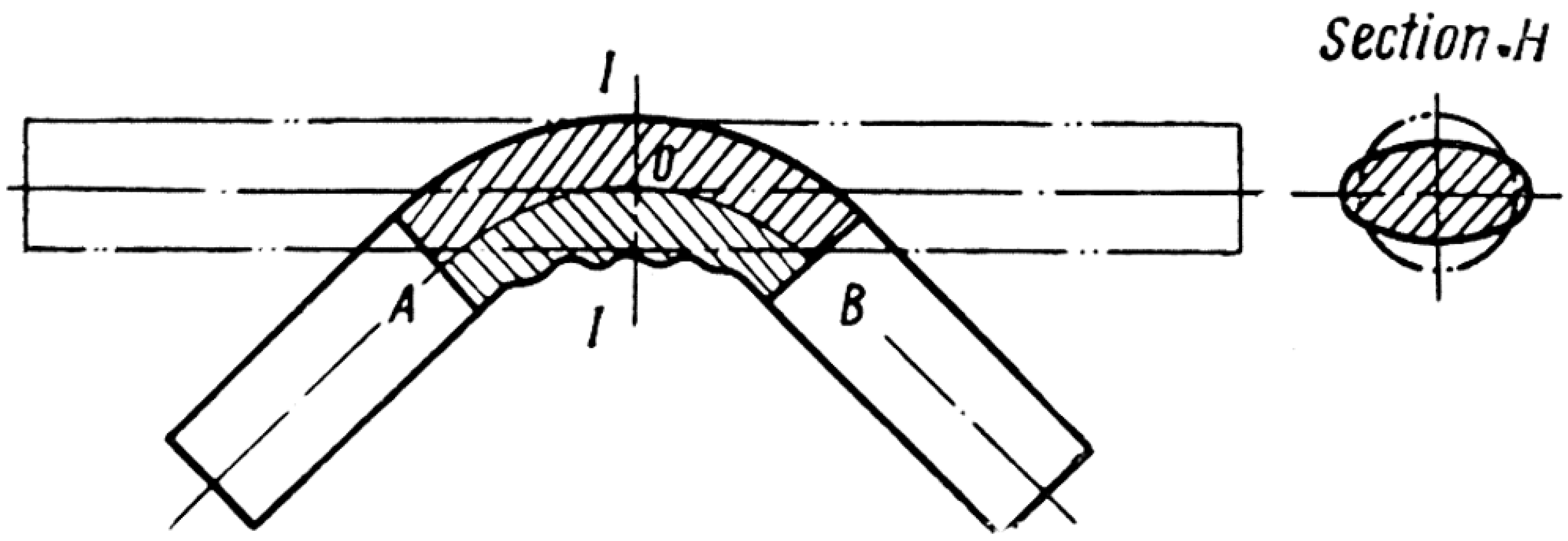


Fig. 101. Location of stresses in bar of steel when bending

subject to tensile stresses, and its inner layers—to compression stresses (see Fig. 101).

Let us consider a bar which has been bent, as in Fig. 101. Before bending, the metal in this bar was distributed uniformly throughout its entire length. After bending, the metal to the left of point *A* and to the right of point *B* in the bar underwent no change whatsoever. But the metal in the section of the bar between points *AOB* undergoes the following changes: the metal lying above the line *AOB* will be stretched, and the further its particles are from line *AOB*, the greater this stretching will be. However the metal below line *AOB* will be com-

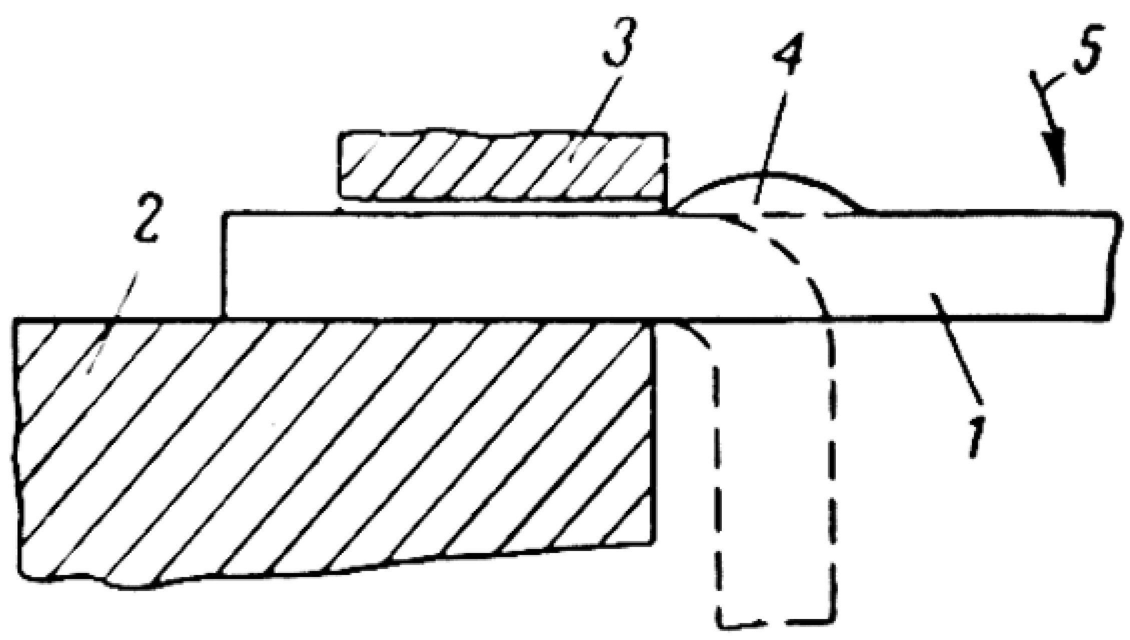


Fig. 102. Bending a previously upset bar:
1) bar; 2) anvil; 3) hammer; 4) upset metal of stock; 5) direction of striking stock

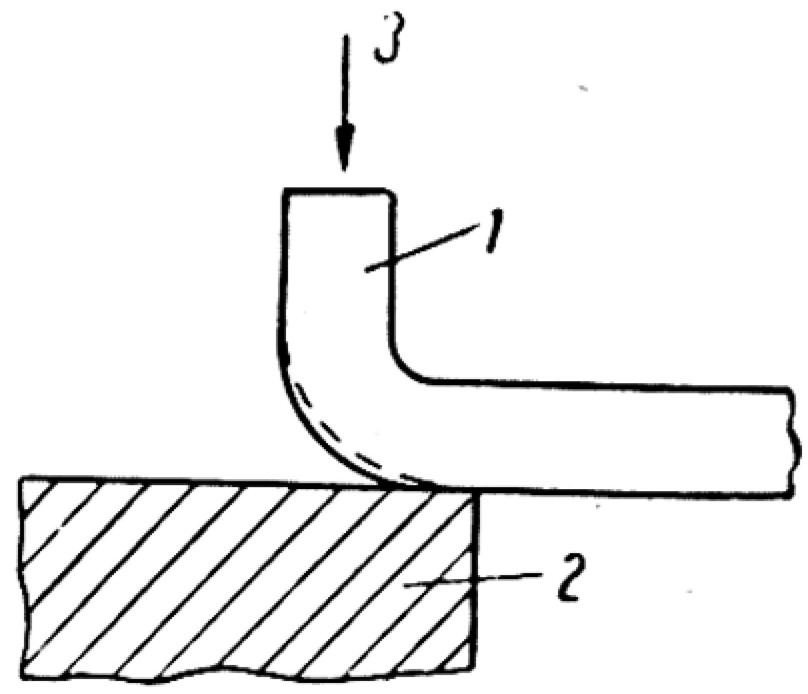


Fig. 103. Upsetting a bar after bending:
1) bar; 2) anvil; 3) direction of blows

pressed, the degree of its compression increasing with its distance below line *AOB*.

The layer of metal lying along line *AOB* will be neither compressed nor stretched; it is called the *neutral layer*.

If the metal is not plastic, or if it was insufficiently heated before bending, cracks may develop on the outer surface of the bent bar, and folds on the inner surface; moreover, the shape of the cross-section of the bar will change after being bent; it will become oval, as shown in Section I-I, Fig. 101. For this reason the following precautions must be taken to preserve the initial cross-sectional shape of the bar when it is being bent.

Before commencing to bend the bar, it *must be upset* at the spot where it is to be bent (Fig. 102). The surplus metal left at this spot after upsetting will help to preserve the initial shape of the cross-section of the bar after it has been bent (Fig. 103).

Only that part of the work which is to be bent should be heated; if a greater length of the work is heated than is actually required, the ends of the heated section will bend and will have to be straightened later. Thin bars of low-carbon steel are often bent without previous heating.

Various devices are used for bending: forks, cramps, links, templates, bolster swage, etc. Fig. 104, *a* shows a fork for bending on anvils; Fig. 104, *b*—a bending link also employed for bending on anvils. In addition, blacksmiths frequently employ *bolster swages*, which greatly lighten bending operations.

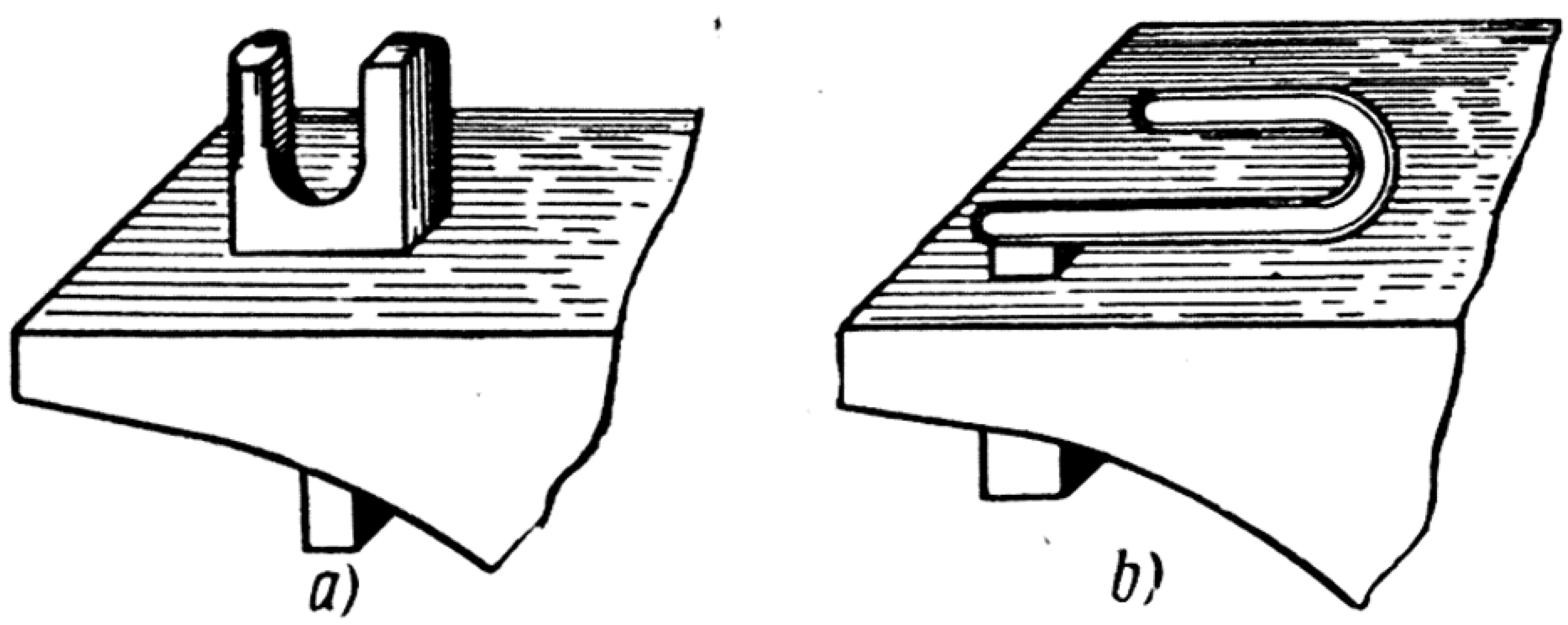


Fig. 104. Bending devices:
a) fork; b) bending link

Fig. 105, *a* shows bolster swage for bending hooks of flat and round steel stock. Fig. 105, *b* shows a *vee swage*, and Fig. 105, *c*—illustrates its use for bending flat stock at right angles.

Below are given some examples of bending operations.

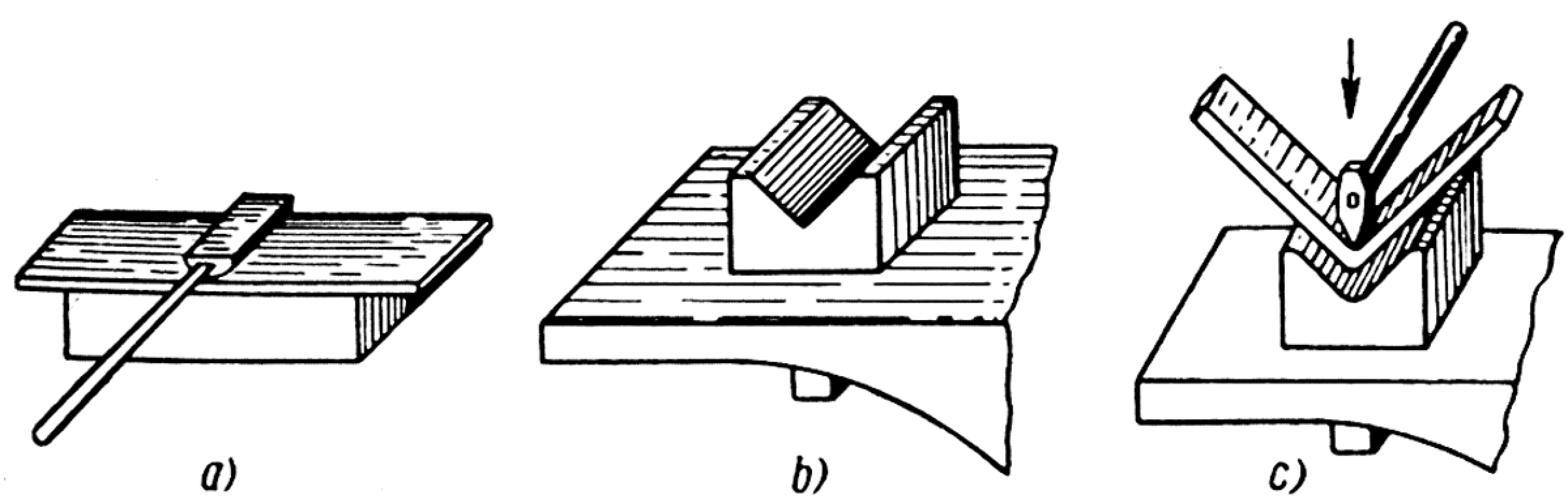


Fig. 105. Bolster swage for bending (*a*); vee swage (*b*); how to use a vee swage (*c*)

Example 1. Bending round bars. To ensure a sound bend when bending round bars or rods, they should be thoroughly heated to red heat, i. e., to about 800°C, at the place where they are to be bent.

Depending on the grade of steel, the heating temperature for bending may be increased; as a rule, the harder the steel, the higher the temperature to which it must be heated.

Forks (see Fig. 106) are very convenient devices for bending round steel bars of not very large diameter. The heated section of the stock is inserted into the fork and is then bent to the required angle by striking its free end with a hand hammer.

Example 2. Bending a flat bar. Flat bars can be conveniently bent with the aid of a bending link or vee swage. Fig. 107 shows how a flat bar is bent with the aid of a bending link. The bending link is placed on the anvil, and the bar—on top of the link, the part to be bent

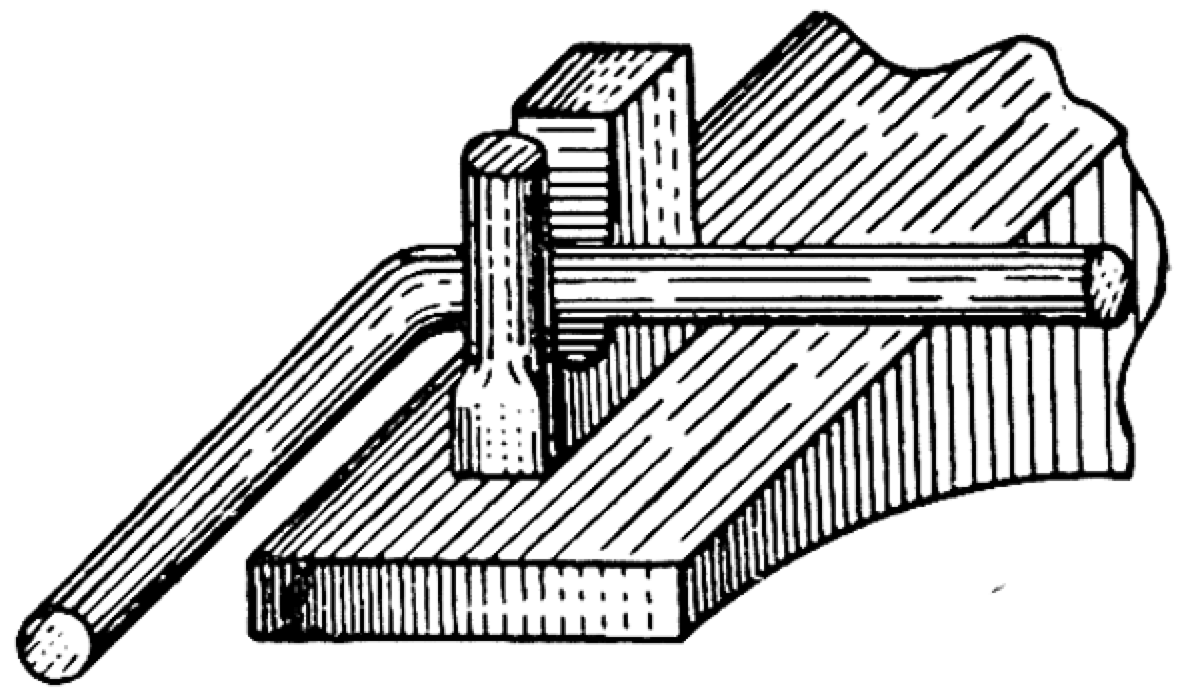


Fig. 106. Bending rod in fork

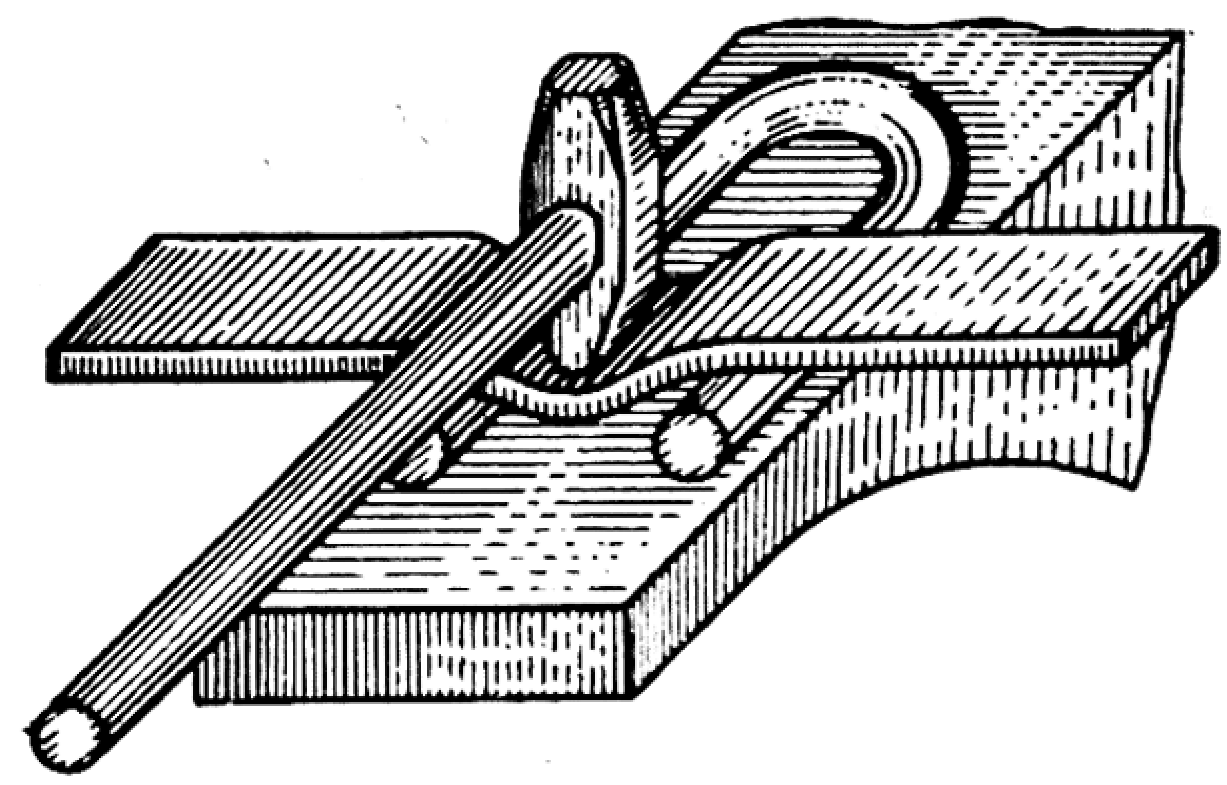


Fig. 107. Bending a flat bar by using a bending link

being placed between the legs of the bending link. The bar is then bent to the required angle by striking a fuller placed on it with a sledge-hammer or hand hammer.

Fig. 105, *c* illustrates the bending of a bar in a vee swage. The method of bending work in vee swages is the same as that used with bending links. The bar must be placed on the link or the vee swage perpendicular to its legs, as otherwise it will be improperly bent. The fuller must always be placed exactly in the centre of the bending link or vee swage.

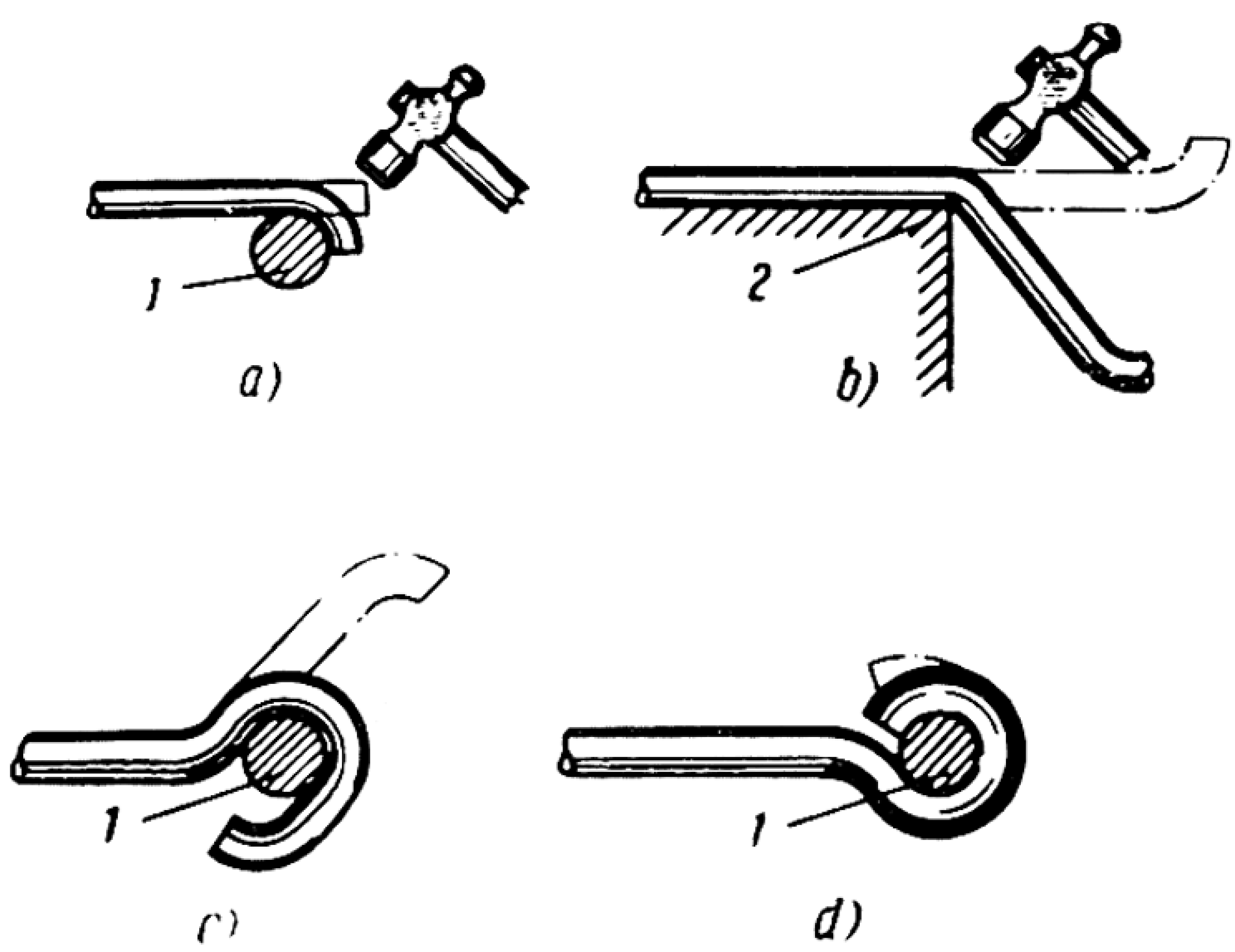


Fig. 108. Bending an eye by using the horn of an anvil:
1) anvil horn; 2) anvil

Example 3. Making (bending) a small eye. The heated end of the stock is placed across the horn of the anvil, and the overhanging end bent as illustrated in Fig. 108, *a*, by striking it with a hand hammer. Then the stock is placed on its edge on the anvil and one end bent to an angle of 60-70°, as shown in Fig. 108, *b*, taking care to make the length of the bent end equal to the length of the eye when developed along its neutral (central) line. The stock is then turned through an angle of 180°, placed across the horn of the anvil and the eye is com-

pleted as shown in Fig. 108, *c*. The work is then turned again through an angle of 180°, placed on the horn of the anvil and its end bent to the required dimensions. The eye is then finished with light blows of the hand hammer (Fig. 108, *d*).

Example 4. Bending a sharp corner. An allowance of extra metal is necessary to ensure a sharp corner at the bend of a piece of work. This extra metal may be obtained by local upsetting. For this purpose the work is heated at the place where it is to be bent, placed upright on the anvil and upset by striking its upper end (Fig. 109, *a*).

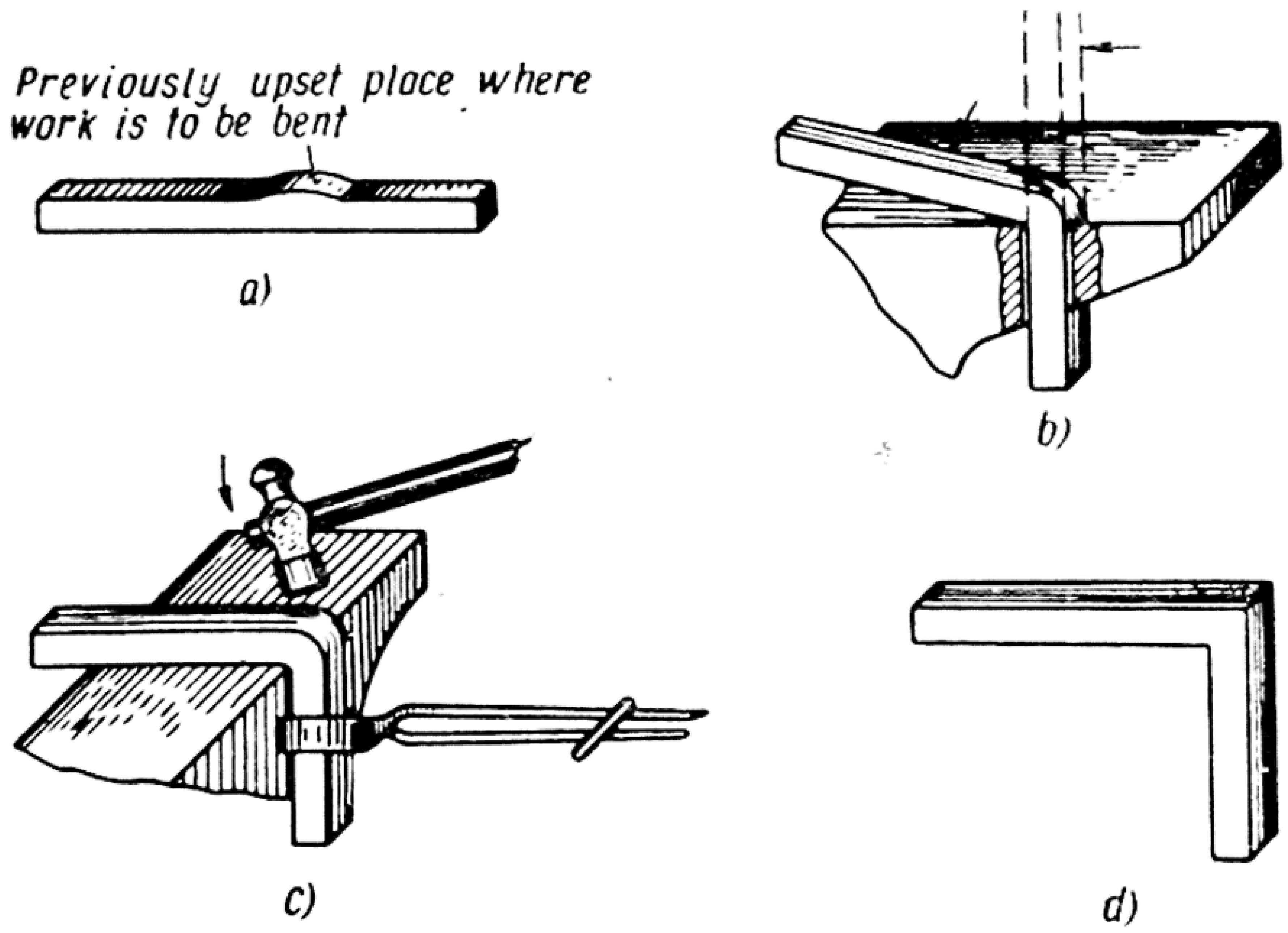


Fig. 109. Bending a piece of work at right angles, with a sharp corner at the bend

If the stock to be bent is very long, it must be upset as follows: the stock is first heated at the place to be upset; it is then struck vertically against a steel plate or supported horizontally against the side of the anvil, and its opposite end struck with a sledge-hammer. The heated section of the stock will then be upset. After upsetting, the stock is straightened on the anvil face and then bent to form a right angle, with the bend, or the apex of the angle in the centre of the upset section. The stock should be placed in the hole of the anvil so that its heated section coincides with the edge of the hole; then its other end is bent over onto the anvil (see Fig. 109, *b*).

Bending blocks are very convenient to use and indispensable in blacksmith's shops. These are massive blocks pierced with holes in which pins can be inserted. Work is bent on these blocks as follows: the work to be bent is placed between a series of pins, previously inserted in the holes (Fig. 110) and bent with a special lever. Work so bent will have no sharp angles. To sharpen the angles of the bends,

the work must first be placed on the anvil as shown in Fig. 109, *c*, and hammered, the direction of hammering being as shown by the arrow in Fig. 109, *d*.

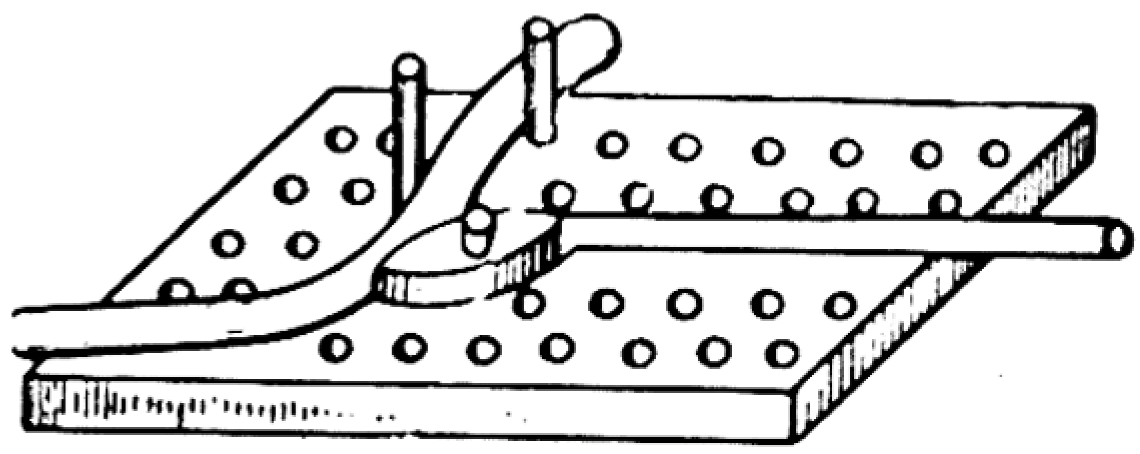


Fig. 110. Blacksmith's bending block

Bending Rolled Sections. Blacksmiths frequently have to bend rolled sections such as angle bars, tee-bars, etc. As a rule, rolled sections are bent against template.

Fig. 111, *a* illustrates a template used for bending angle bars on an anvil, while Fig. 111, *b* shows a method of bending an angle bar. The angle bar, after being heated, is secured to the edge of the template with a movable clamp, and bent to the required shape by striking its free end with a sledge-hammer. During the bending process wrinkles will be formed on the angle bars; these can be smoothed out with the aid of a flat smoother. After smoothing (finishing) the bent section of the angle bar, the clamp must be shifted further and the bending continued to the required length.

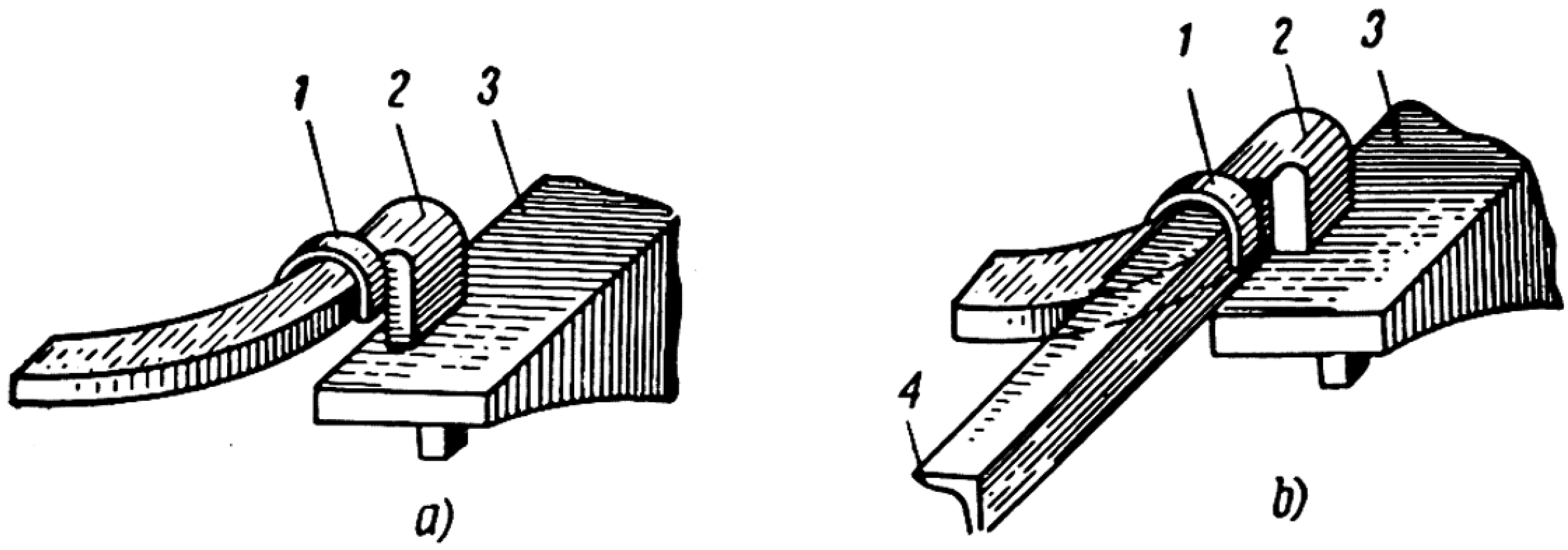


Fig. 111. Template (*a*) and scheme of bending an angle bar (*b*):
1) shackle; 2) template; 3) anvil; 4) angle bar to be bent

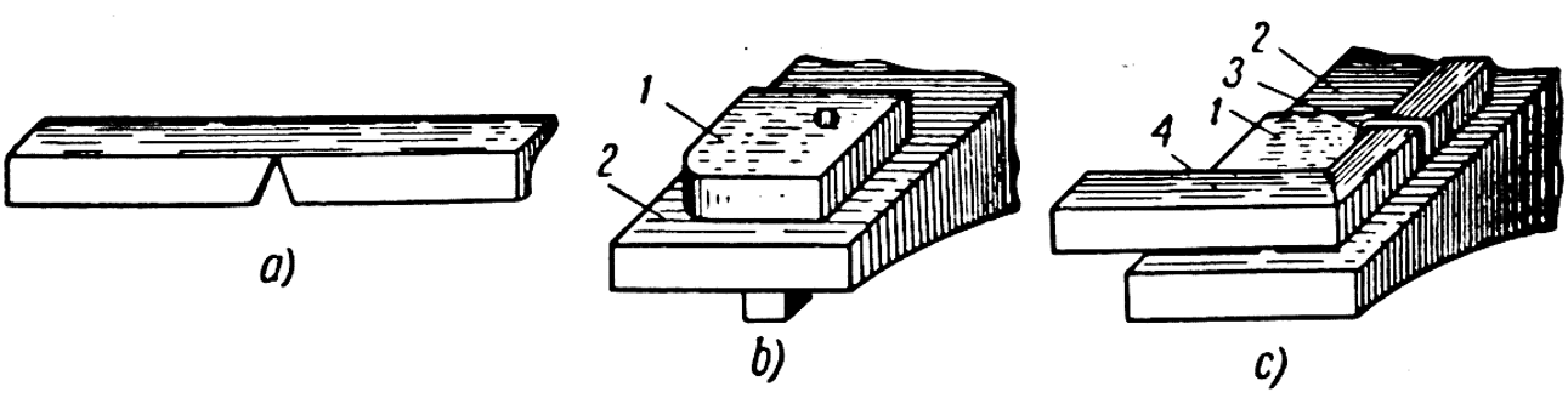


Fig. 112. Bending an angle bar at right angles, with a sharp corner at the bend:
1) template; 2) anvil; 3) shackle; 4) angle bar

Should it be required to bend an angle bar to a sharp corner, one of the webs of the angle bar must first be notched, as shown in Fig. 112, *a*. The angle bar can then be bent to the required shape with the aid of a template (Fig. 112, *b* and *c*). After bending, its webs must be smoothed (finished) with the aid of flat smoothers.

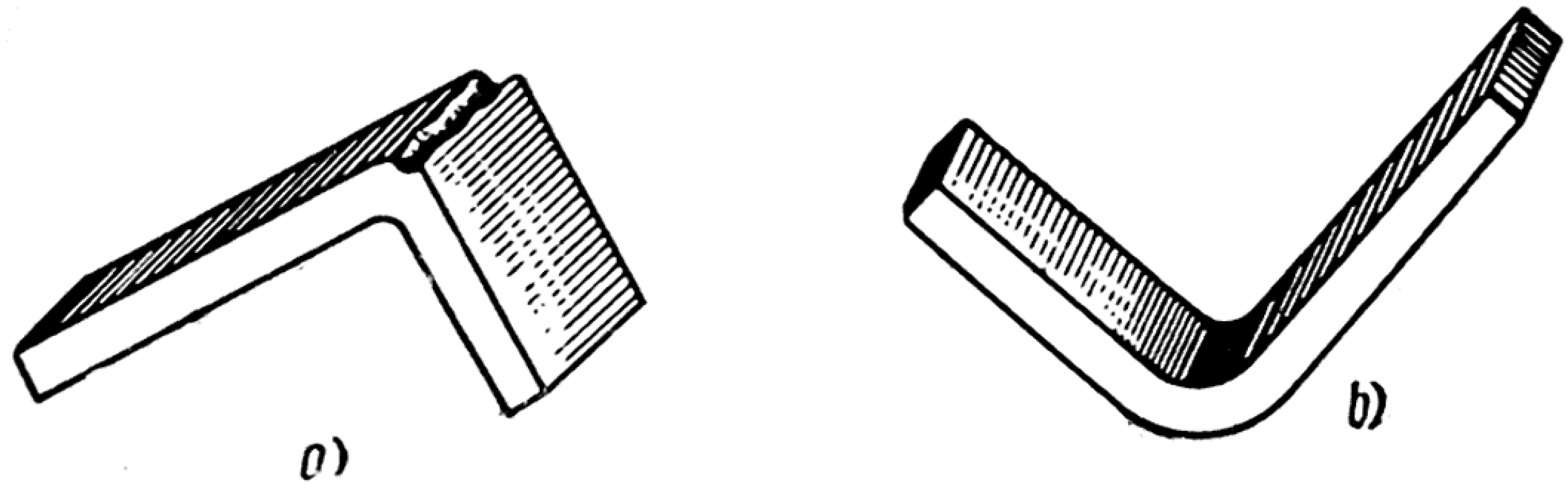


Fig. 113 Bending defects: a) tears; b) reduction of metal

Bending Defects. The following defects may occur during bending:

1) *Rupture of the metal.* This occurs either if the stock has cooled down during bending, or if it has not been properly heated before the bending was started (Fig. 113,*a*).

2) The *work becomes thinner at its bending point*. This results if the work is not upset before bending (Fig. 113, *b*).

PUNCHING AND PIERCING HOLES

Punching and piercing are employed for making holes in work during forging.

Holes in a thin work are made by *piercing*; for this the metal (previously heated to 900-1,000°C) is placed on anvil *5* (Fig. 114) so that the place to be punched coincides with the hardie-hole in the anvil; or work piece *2* is placed over ring *3*, the inside diameter of which is slightly greater than that of the required hole. Punch *1* is then placed over the spot to be pierced, and its head struck with a sledge-hammer. The punch will cut through the steel almost without spreading the metal surrounding the hole. When the punch passes through the metal, it forces the cut piece of metal, called the slug *4*, through the hardie-hole or the ring *3*; the height of the slug will be almost the same as the thickness of the work being pierced.

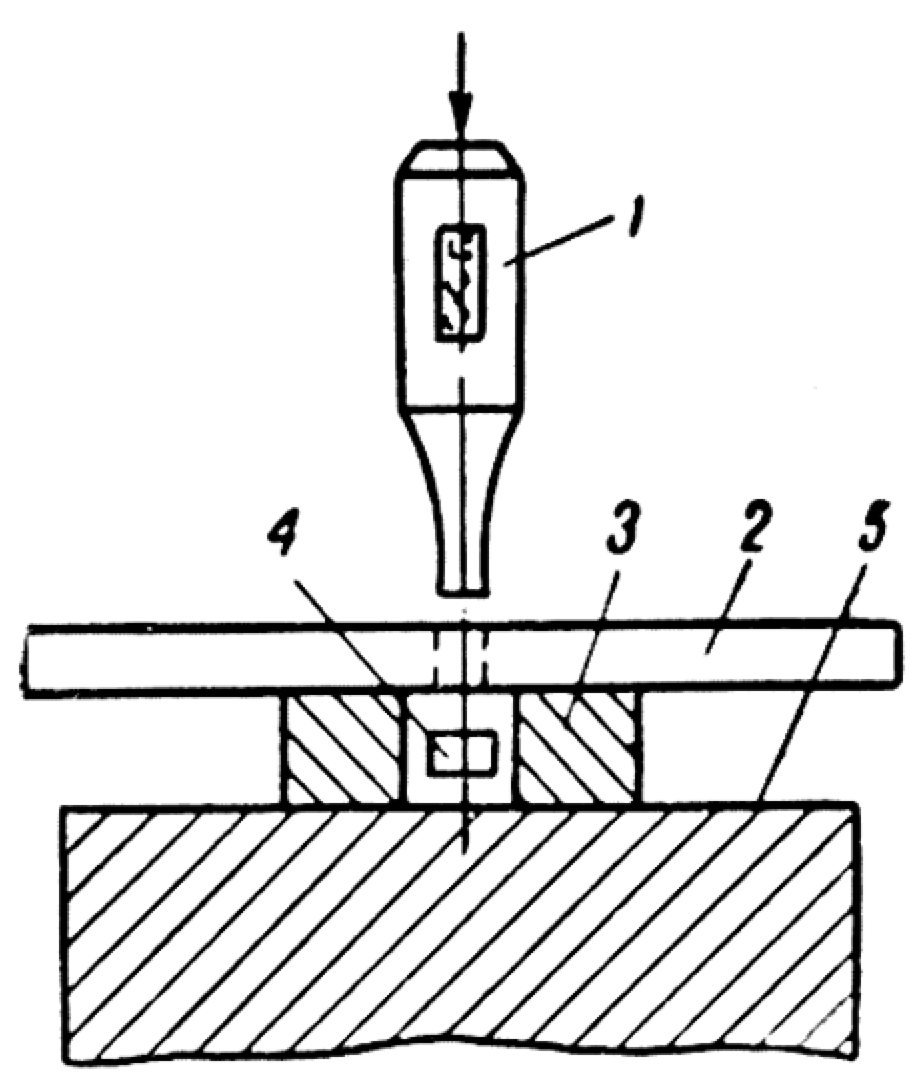


Fig. 114. Punching a hole in a bar with a punch

In thicker works holes are *punched*. The process of punching holes is altogether different from that of piercing.

First of all, the work, after being heated to 900-1,000°C, is placed on the anvil so that the location of the hole which is to be made coincides with the hardie-hole. A punch is then placed on this spot. The punch *1* is forced about half-way through the work *2* by striking it lightly with a hand- or sledge-hammer until a bulge is formed on the underside of the work (Fig. 115, *a*). The punch is then removed, the

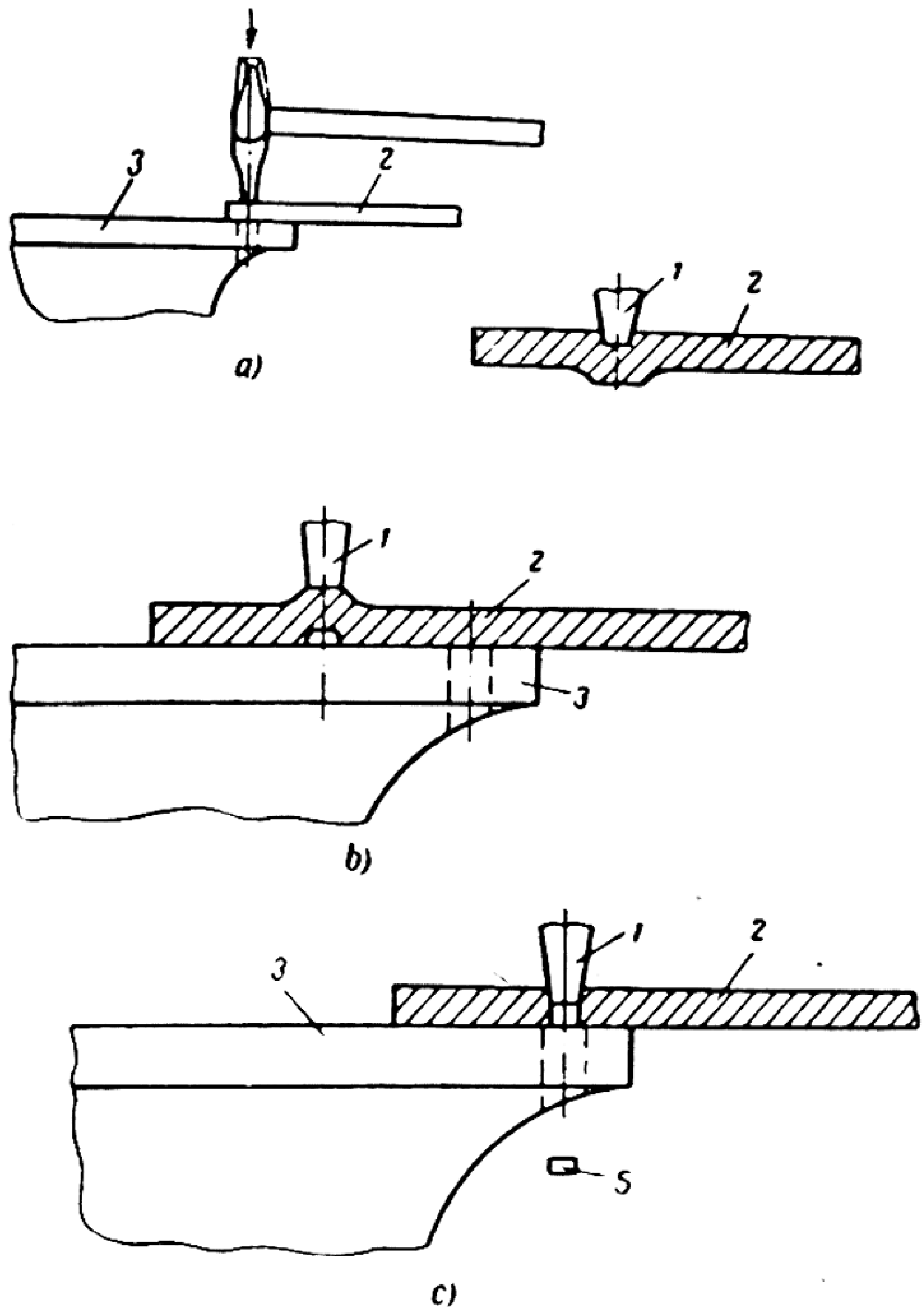


Fig. 115. Piercing a hole in a bar with a piercer

work turned over, the bulge struck several times with a hand hammer, the punch placed on the bulge (Fig. 115, *b*) and driven into the metal by the sledge-hammer.

The resulting slug *5* can then be driven out through the hardie-hole of anvil *3* by striking the punch with the sledge-hammer.

When making holes with punches, the metal spreads, thus resulting in changes in the shape of the forging.

Holes are punched if they are to be made at the beginning of the work, i. e., before it is completely forged. On the contrary, holes are pierced if they are to be made in a nearly finished forging, as the shape of the work is practically unchanged after piercing.

During hand forging, holes are punched or pierced in steel with the aid of *punches* or piercers. The working ends of these tools can be either square (Fig. 116, *a*) or round (Fig. 116, *b*), and are always tapered—both to facilitate its withdrawal from the hole, and for making holes of various sizes. They are fitted to wooden handles. When making holes, the head of the punch is struck by a hand- or sledge-hammer.

The *swage-block* (Fig. 117) is used for making holes in forgings. Swage-blocks are square, massive blocks of steel or cast iron, with holes of different shapes and sizes. The blacksmith selects a suitable hole, places the heated work over it, and punches the required hole with the proper tool. The sides of the swage-block are made with recesses of different shapes, designed to shape and smooth forgings; this is done by placing the heated work in the selected recess and a smoother, or top swage, over it, and then hammering the smoother or top swage as required.

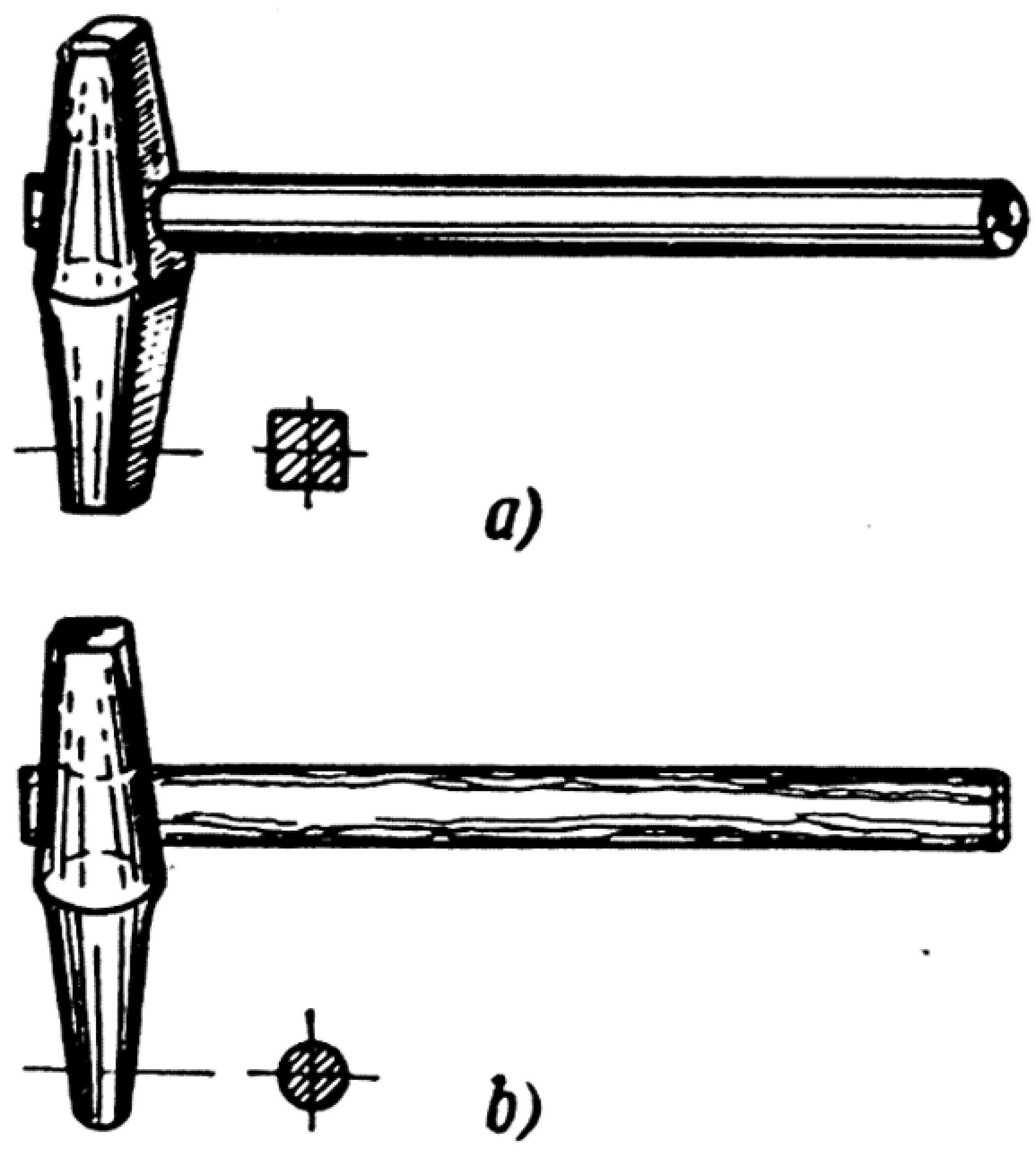


Fig. 116. Blacksmith's punches

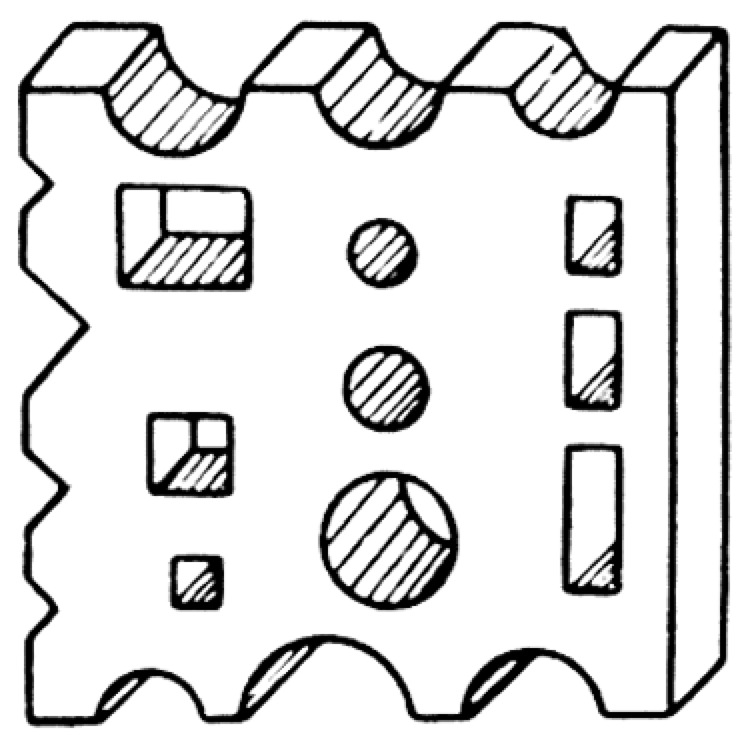


Fig. 117. Swage-block

The steel must always be hot for punching or piercing holes. The spot to be punched or pierced must be heated to an orange-yellow heat, which corresponds to about 900-1,000°C. It is not recommended to punch or pierce holes in cold steel, even in a thin work, as this may lead to cracks and burrs developing at the edges of the hole.

The punch should always be placed exactly upright on the work and the first blow of the sledge-hammer on its head should be a light one. A heavy, slanting blow may cause the punch to fly out of the blacksmith's hand and injure bystanders. After each blow, the punch should be shaken slightly, to prevent it from sticking into the steel.

If the work is very thick, the punch should be removed from time to time, and its point cooled in water. Otherwise, it will become heated and will bend without piercing the steel.

Powdered charcoal should be sprinkled inside the hole being punched; the gases evolved by the burning charcoal will prevent the punch from sticking in the steel.

After punching or piercing, the walls of a hole will never be exactly vertical. This is because the punch or drift is tapered.

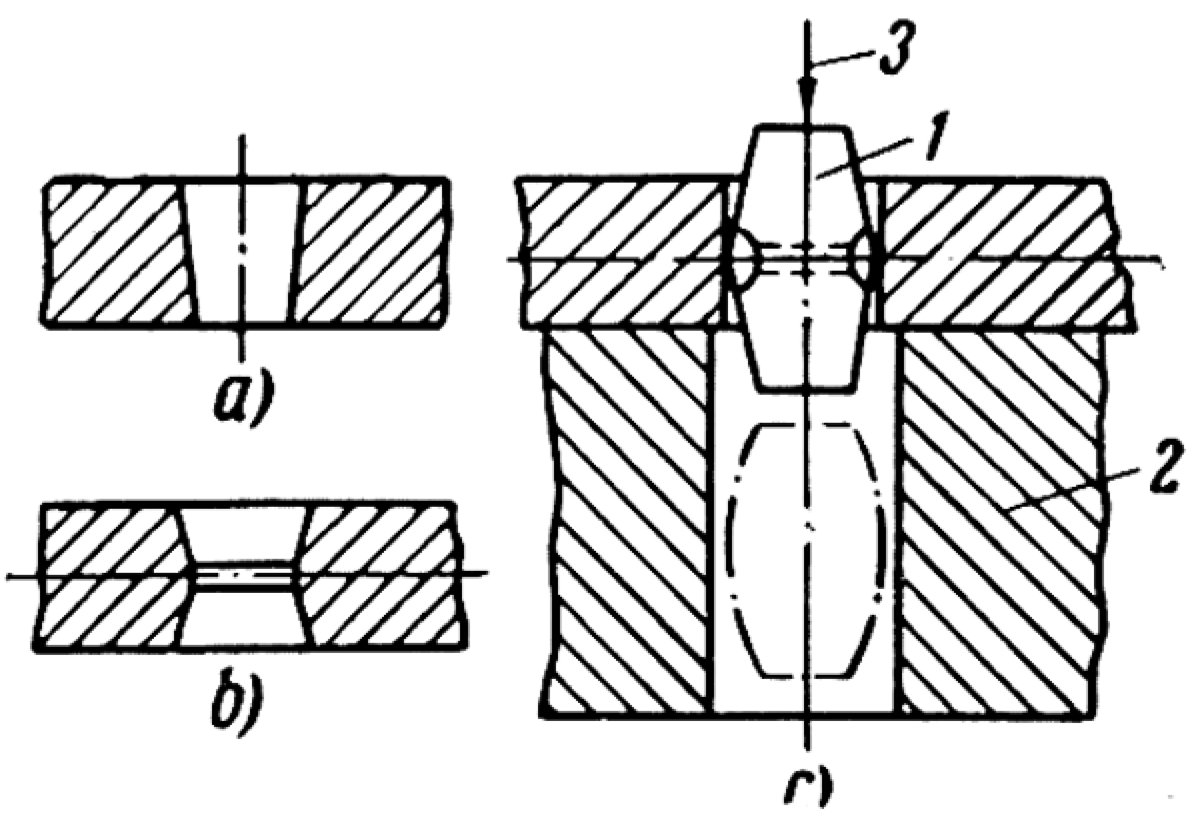


Fig. 118. Drifting (widening) and smoothing the walls of a hole:
1) drift; 2) ring

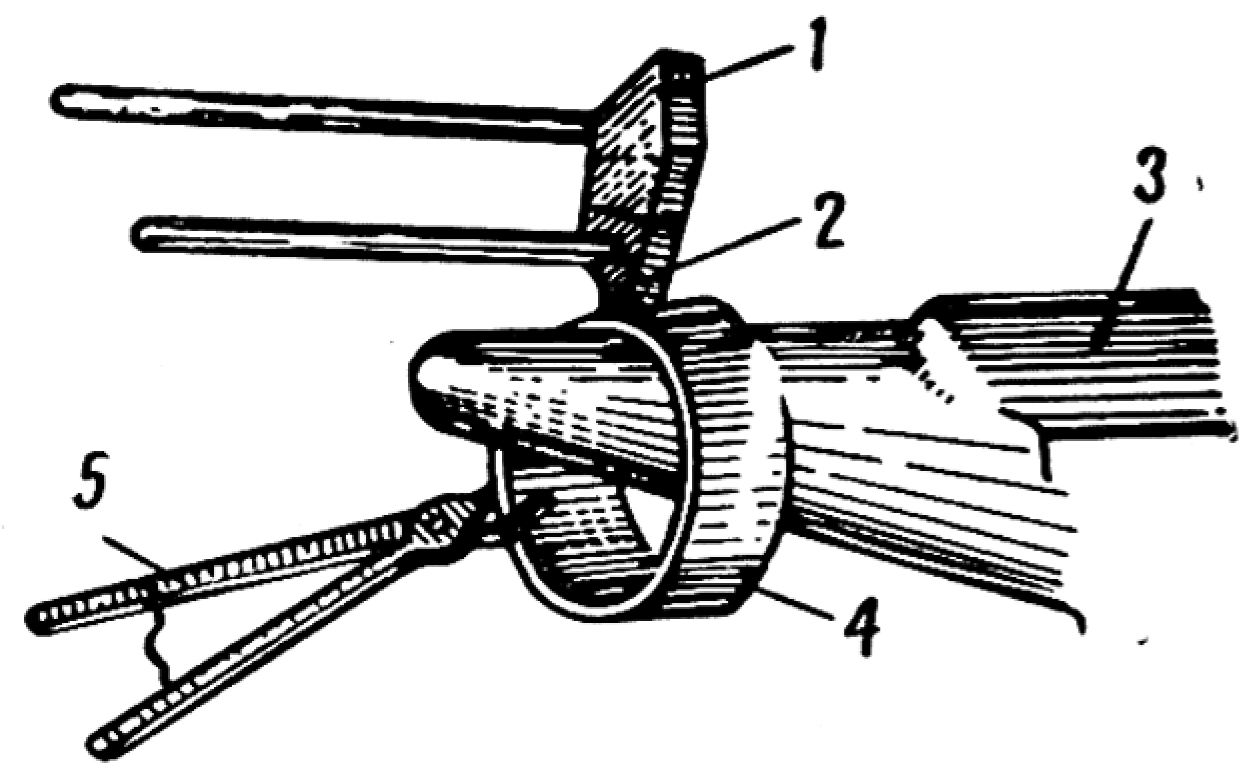


Fig. 119. Spreading a ring:
1) sledge-hammer; 2) half-round faced hammer (fuller); 3) anvil; 4) ring; 5) tongs

Fig. 118, *a* shows a pierced hole, and Fig. 118, *b*—a punched hole. The walls of holes thus made must be smoothed, and the hole given a proper circular shape, by forcing a barrel-shaped drift through it, as shown in Fig. 118, *c*.

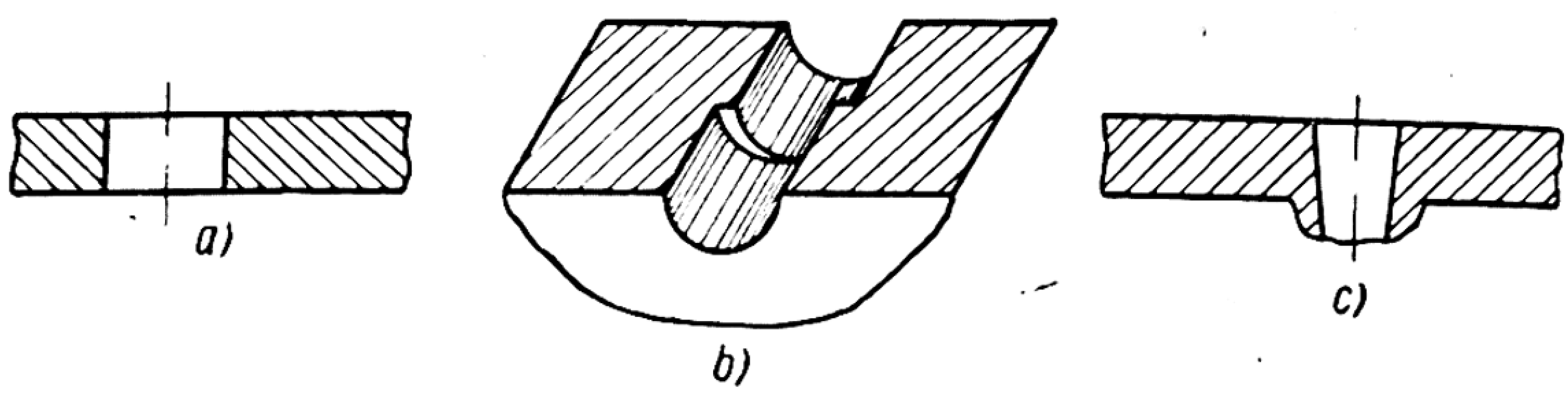


Fig. 120. Defects occurring when punching and piercing holes

After punching, a hole can be widened if necessary by driving a *drift of barrel-shaped cross-section* through it. Sometimes several drifts (or mandrels) of increasing diameters have to be used. Seamless rings can be made in this way. To do this, after the diameter of the hole of the ring has been sufficiently increased with the drifts, it is placed over the horn of the anvil (Fig. 119), and its inner diameter increased by reducing the thickness of its walls. This is effected by striking the ring with a hand hammer or with a sledge-hammer, the ring being rotated all the time over the anvil horn. The walls of the ring will be drawn out, and the diameter of the hole will be increased. This operation is called rolling or saddling.

Defects Which May Occur During Piercing or Punching. The following defects may occur during punching or piercing:

1) *The hole may be out of centre* (Fig. 120, *a*); this may occur when piercing a hole in a thick piece of work in one operation, without turning it over;

2) *The opposite sections of the hole may not be in line* (Fig. 120, *b*) due to improperly placing the punch on the work after the latter has been turned through 180°;

3) *Burrs may occur* (Fig. 120, *c*) if the diameter of the hardie-hole of the anvil, swage-block or ring is considerably greater than that of the hole being pierced;

4) *Tears and cracks may occur* at the edges of the hole as a result of punching or piercing cold or insufficiently heated work.

FORGE WELDING

Forge welding is a process whereby two pieces of metal, heated to a plastic condition, are joined together under external pressure. As has been learned, steel, on being heated to a definite temperature, becomes highly plastic; if the temperature of two pieces of steel is raised until their surfaces become pasty, and they are then pressed or hammered together, they will be welded, i. e., form a single piece of steel.

If two pieces of steel are properly welded together, the tensile strength of the resulting single piece of steel at its welded joint must be equal to that of the parent metal, that is, to the tensile strength of either of its two separate pieces. As a matter of fact, however, it is impossible to attain a perfectly close contact of all the particles of the steel being welded; and for this reason, the tensile strength of a welded piece of work at its joint is usually less than that of its two separate components. A weld is considered as being sound if the tensile strength of the welded joint is not less than 85 per cent of the tensile strength of the parent metal.

Welding is employed chiefly when the forging of a whole piece of work presents difficulties. In such cases, separate parts of the work are forged and then welded together. Welding is also widely practised in repairing operations.

Forge welding consists of the following separate *operations*: 1) preparing the ends of the pieces to be welded together; 2) heating them for welding; 3) welding the ends together; 4) hammering and finishing the weld joint.

The weld joint must be thoroughly hammered. In order that, after welding and hammering, the cross-section of the work should be the same as it was before welding, the ends of the pieces to be welded must be first *upset* and then *hammered*, depending on the welding

method employed. After the ends have been prepared for welding, they must be heated to welding temperature. This is usually done in the hearths or in special welding furnaces. As a rule, forge furnaces are not suitable for heating steel for welding and are unable to ensure the required welding temperature. The best fuels for weld heating are charcoal and coke. Coal is also used for weld heating, but only if its sulphur content is less than 1 per cent, as sulphur is detrimental to high-quality weld joints.

Welding temperatures range from 1,275 to 1,400° C, i. e., they are considerably above the initial temperature of ordinary forging. This high temperature ensures the better joining of the parts being welded. The welding temperature depends on the chemical composition of the steel: the greater the content of carbon and alloying elements in the steel, the lower must its welding temperature be. The heating of low-carbon steels must be stopped when the ends of the parts to be welded are at a blinding white heat; of high-carbon steels — when they are at white heat, tinged with yellow. The welding temperature is generally determined with the aid of optical pyrometers; and sometimes by the naked eye.

The heating of steel to be welded demands considerable attention and care. It is absolutely necessary that the places to be welded together are free of scale, slag, etc., i. e., the surfaces of the steels to be welded must be absolutely clean. Cleanliness of the surfaces to be welded is a most important condition for ensuring sound welds, as all foreign matter (slag, scale, etc.) will prevent intimate contact of the particles of steel, thereby lowering the mechanical strength of the welded joint. The steel must be heated in such a way as to avoid an oxidising flame in the hearth or in the furnace; in other words, the flame should be free of any traces of excess air; the steel being heated must also be covered with a layer of slag to protect it against direct contact with the flame. To achieve this the surface of the steel must be sprinkled during the heating with what is called flux. Screened fine river sand mixed with borax can be used for flux.

The flux melts very rapidly to form a slag which protects the surfaces of the steel being welded. It also dissolves any scale which may have formed before it was sprinkled on the steel. After heating the ends to the necessary welding temperature, they must be quickly taken out of the hearth or furnace, struck against the anvil to remove all slag which may have stuck to their surfaces, rapidly cleaned with a steel brush or scraper and no less rapidly placed on each other and then hammered, lightly at first, and then heavily, with a hand- or sledge-hammer. The pieces of steel will then come into intimate contact and be welded, i. e., they will join to make a single piece of steel.

Vigorous hammering of the welded parts is also necessary in order to ensure sound welds. When forge welding, the work must be hammered quickly and heavily, as only thus will an intimate contact between the particles to be welded be ensured at the highest possible temperatures. Moreover, the grain structure of the welded parts of the steel is coarsened when the steel is heated to welding temperature; vigorous hammering breaks up and refines the grain, thereby improving the quality of the weld joint.

It should be remembered that a sound weld can only be ensured at a proper high temperature and therefore welding should be completed at this temperature. This can only be ensured when the welding is done quickly.

The last operation in forge welding is the *finishing* of the weld joint; this is effected with the aid of swages and fullers, depending on the shape of the welded work and the method of welding.

Not all metals possess what is called *weldability*. For instance, lead cannot be welded. By no means do all steels possess good weldability. The less alloying element in a steel, the better it welds. Pure iron is highly weldable, but any alloying element lowers this property. The higher the carbon content, the poorer the weldability of a steel. The weldability of steel likewise decreases with the increase of the phosphorus, sulphur, chromium and copper content, etc. A manganese content up to 0.6-0.8 per cent improves weldability, and for this reason manganese steels intended for welding may have an increased carbon content.

The following maximum contents of alloying elements are recommended for ensuring sound welds: carbon—from 0.2-0.3 per cent, but not exceeding 0.5 per cent; silicon—not more than 0.2 per cent; manganese—0.6-0.8 per cent; phosphorus and sulphur—as low as possible, but not more than 0.05 per cent of each. If it is necessary to weld a steel containing over 0.2-0.3 per cent of carbon, filings of some mild steel having a small carbon content must be added to the welding flux. This will result in the decarburisation of the steel at the joint, thus ensuring a better weld.

Welding Methods. The chief methods of welding parts are: 1) butt welding; 2) lap welding; 3) fork and wedge (cleft) welding; 4) tee-joint welding; 5) vee welding.

Butt welding entails the following operations: slightly upsetting the ends of the pieces of steel to be welded and then slightly rounding the faces of the ends (Fig. 121, *a*). The upsetted ends are rounded off in order to facilitate removing the slag formed on their surfaces when they were heated to welding temperature. Then both ends are heated to welding temperature. The blacksmith and his striker each take one end of the work in their tongs, place the heated ends close to each other (Fig. 121, *b*) and strike the opposite, cold ends, of the work

with sledge-hammers, thereby welding the ends together (Fig. 121, *c*). This done, the weld joint must be well hammered and finished with swages and smoothers.

Lap welding is a more reliable method than butt welding. Before welding by this method, the ends of the work are upset, and then hammered or scarfed as shown in Fig. 122, *a*. Then the ends are heated to welding temperature and cleaned from slag and scale; after which one scarfed end is imposed over the second as shown in Fig. 122, *c*,

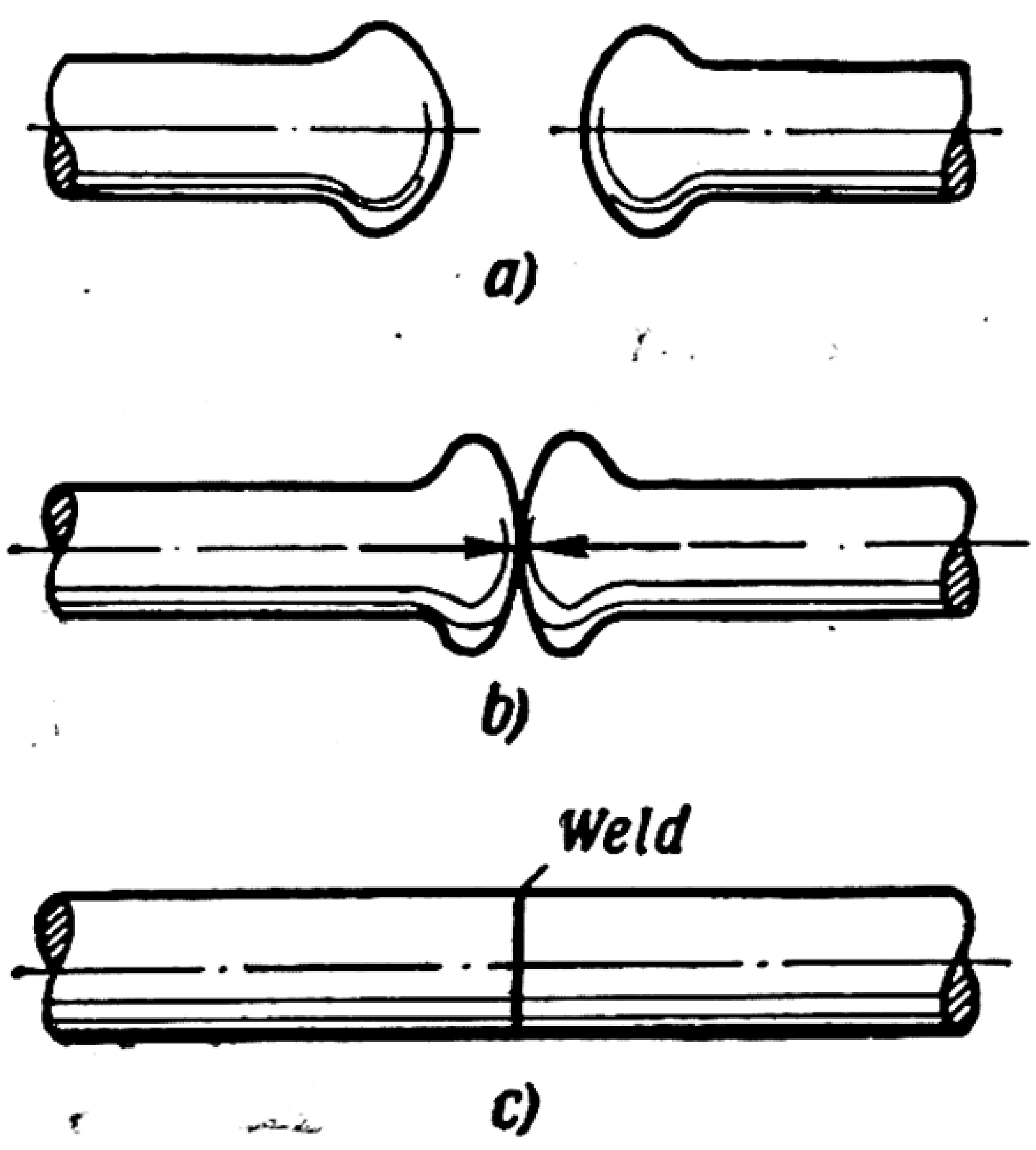


Fig. 121. Butt welding

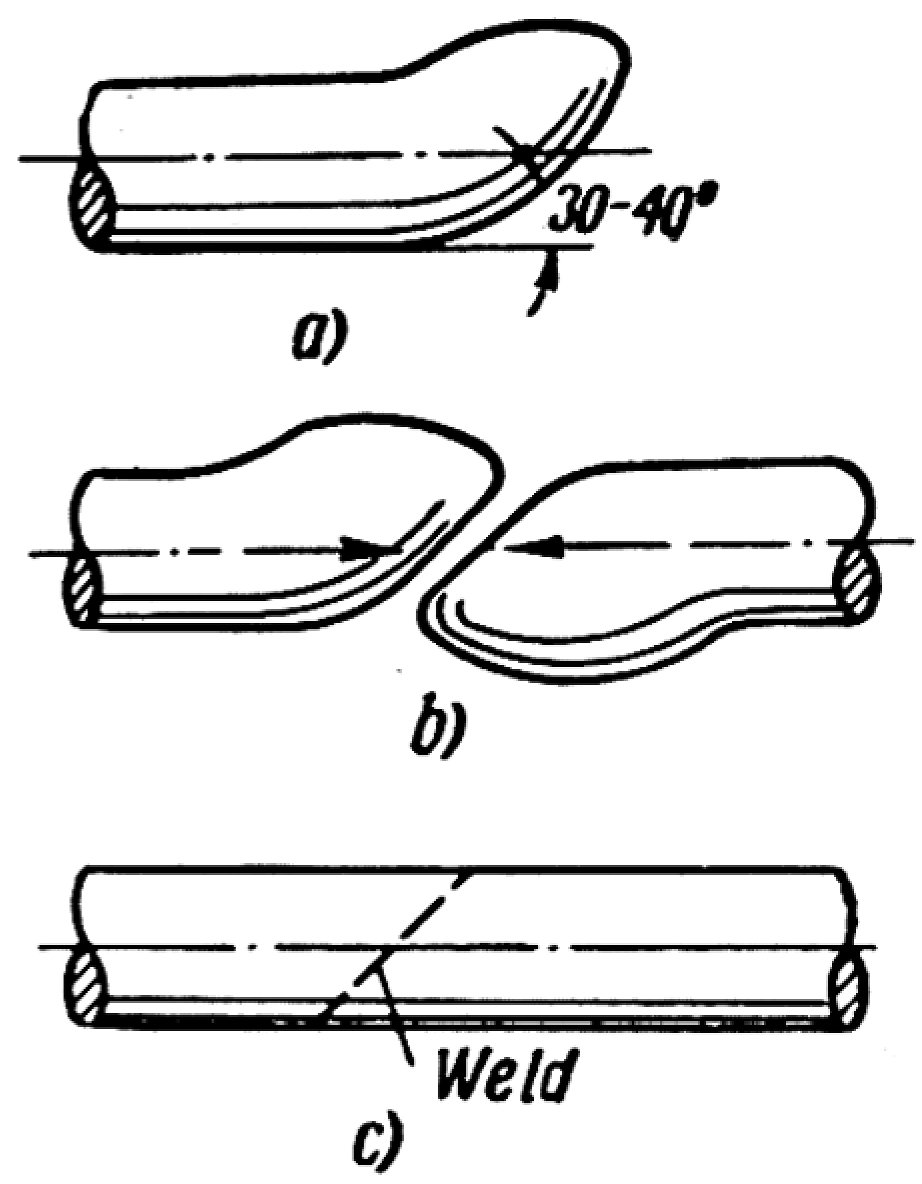


Fig. 122. Lap welding

and both ends hammered and welded together. The weld joint is then finished with the aid of swages and smoothers; the resulting bar will then look as illustrated in Fig. 122, *c*.

Fork and wedge, or *cleft welding* is employed for joining parts of heavy cross-section or for welding two pieces of different grades of steel.

By this method, the end of one bar, preferably that of the softer steel, is heated and upset; the upset end is then split and opened, as shown in Fig. 123, *a*. The end of the second bar, after being upset, is hammered to a point as shown in Fig. 123, *b*. Both ends are heated to welding temperature and cleaned from slag and scale. The pointed end is inserted into the fork of the end of the first bar (Fig. 123, *c*). The weld joint is then hammered and finished with swages and smoothers. If two pieces of steel of different grades are to be welded, their welding temperatures will differ and for this reason they should be heated in separate hearths.

Tee-joint welding is a method of welding two parts to form a tee-joint (Fig. 124).

Vee-welding is employed for joining heavy parts. The ends of parts *a* and *b* are first upset and cut to a taper of approximately 30-40°, as shown in Fig. 125. Then two inserts *c* of the same grade of steel are forged to the same taper angle as the parts to be welded. The ends to be welded are heated to welding temperature after which the inserts,

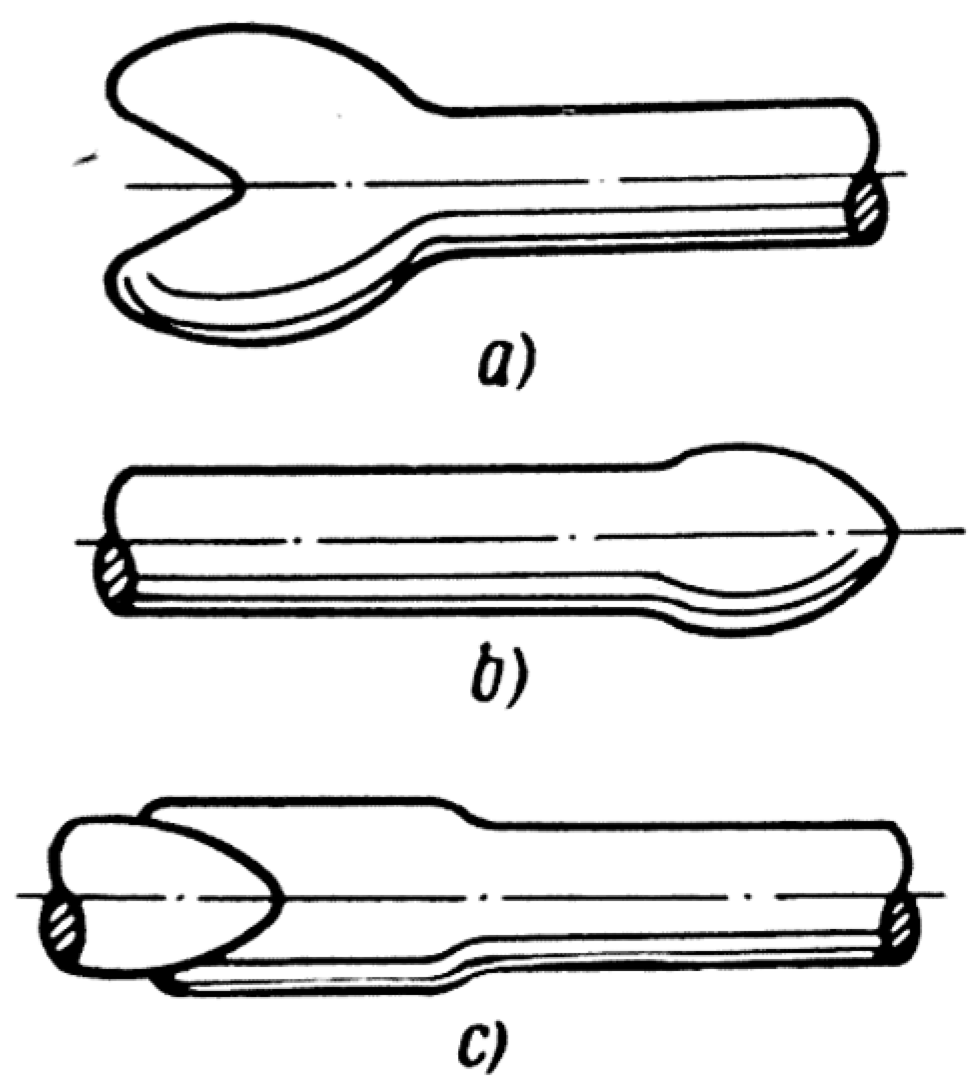


Fig. 123. Fork and wedge or cleft welding

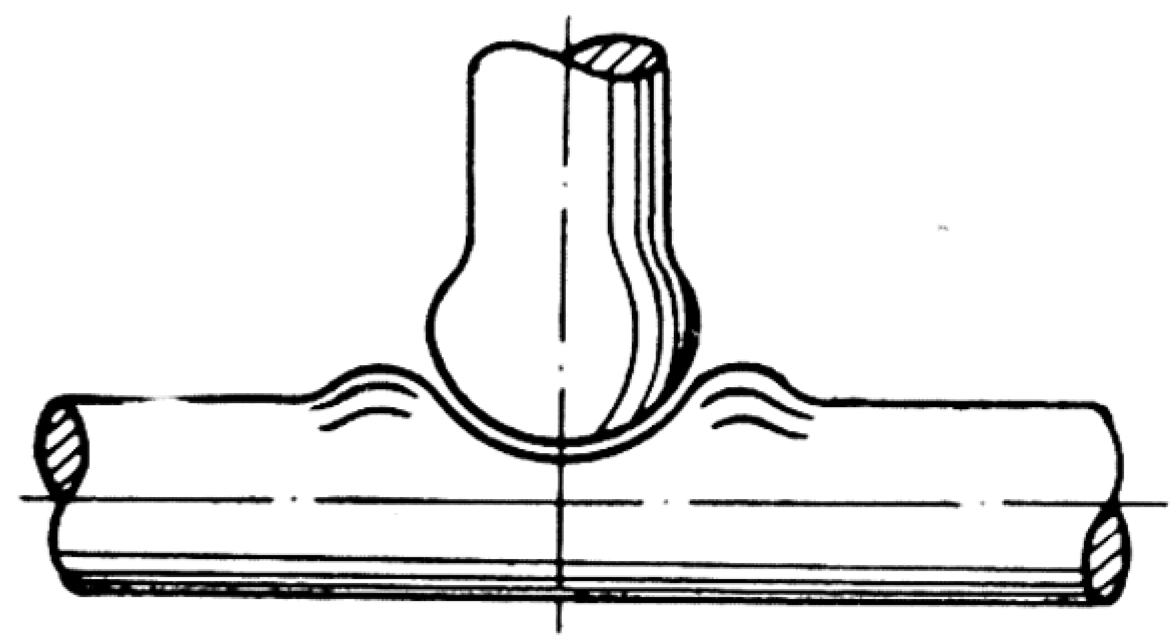


Fig. 124. Tee-welding

also brought to the welding heat, are placed in the triangular space between the ends of *a* and *b*, and the entire work is hammered with a sledge-hammer. This method is very convenient for welding circular parts, particularly when repairing broken rings.

Inspection of Welds, Welding Defects. A weld is considered as being sound if the tensile strength of the welded joint is at least 85 per cent of that of the parent metal. As a rule, the tensile strength of a weld joint is from 60 to 80 per cent of that of the parent metal.

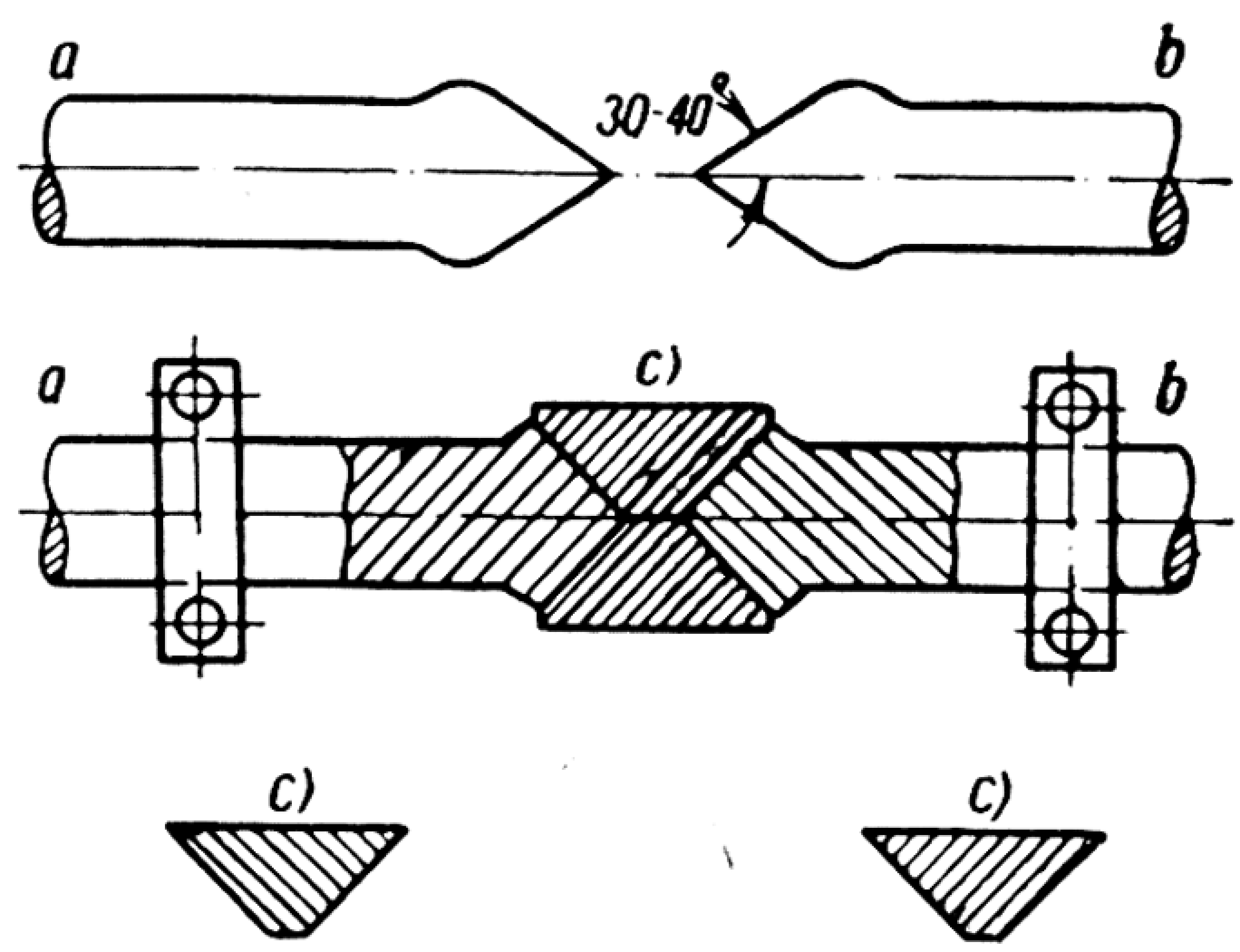


Fig. 125. Vee-welding

The strength of a weld joint is determined by mechanical tests, for which purpose test specimens are cut out and prepared from steel of the same grade as that used for making the welded work. In practice, the quality of a weld can be checked by bending the bar at the weld joint. If, on bending, the joint does not separate, i. e., it does

not display signs of cracks, the weld is considered as being sufficiently good.

The surface of a weld must be even and smooth. However, the following defects may occur in a weld joint:

1) *Incomplete fusing*, which may be due to scale left on the surface of the ends being welded; for this reason, scale must always be completely removed, and the ends to be welded must be sprinkled with flux (mixture of quartz sand and borax);

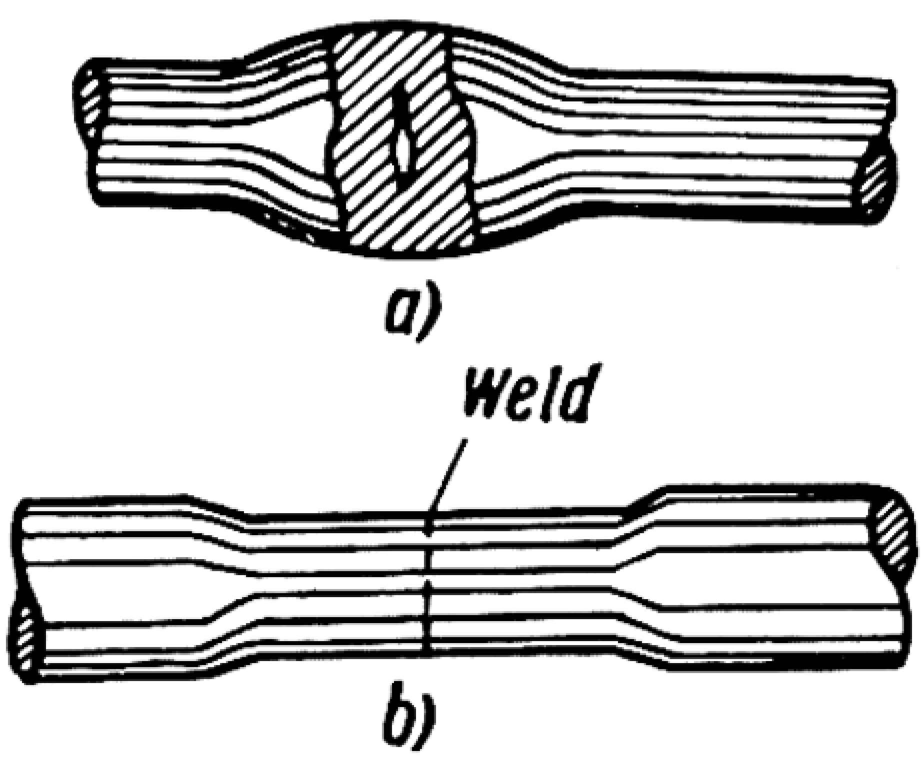


Fig. 126. Welding defects

2) *Incomplete weld* (Fig. 126, *a*). This may be due to slag and scale on the ends of the work if they have not been rounded off, thereby preventing proper welding; this generally occurs during butt welding;

3) The *thickness* (*cross-section*) of the work at the weld joint is less than required (Fig. 126, *b*). This is a result of not upsetting the ends of the bars before welding, the cross-section of the welded bar at its joint is therefore reduced when hammered;

4) *Burns*, which occur when the ends of the work to be welded are heated to an excessively high temperature.

The very nature of the above-mentioned welding defects shows that they depend chiefly upon the blacksmith himself. It is difficult,

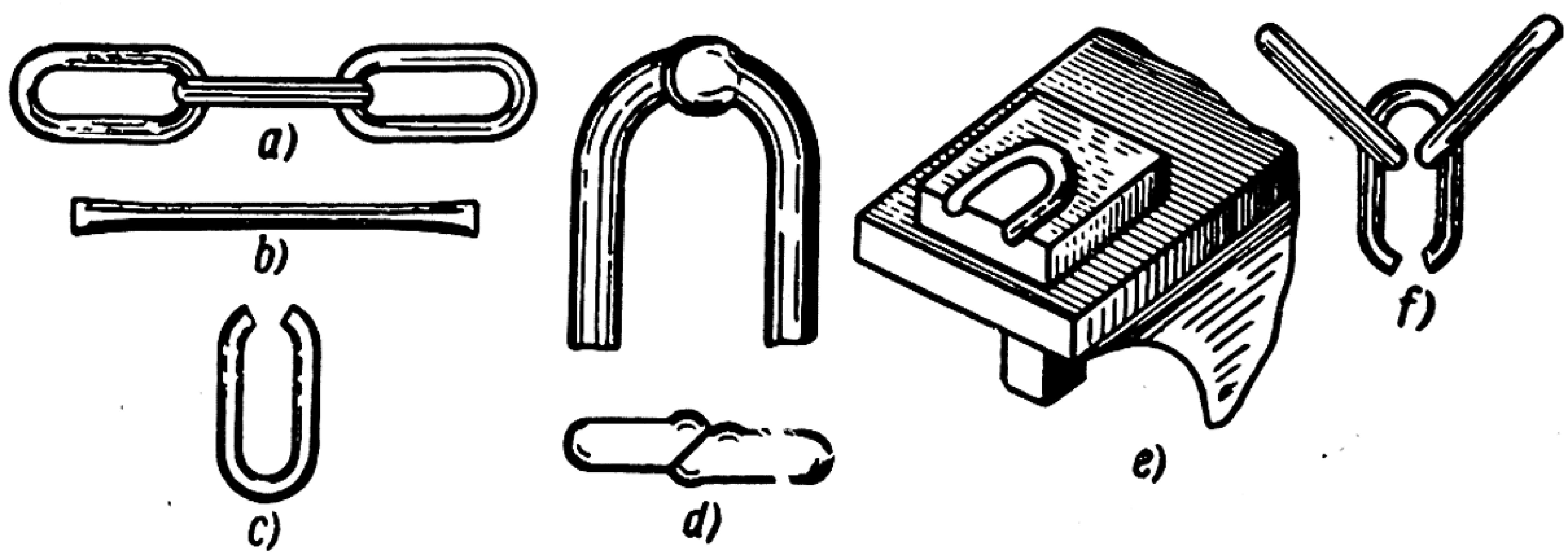


Fig. 127. Making a welded chain

if not impossible, to remedy these defects after welding, and for this reason such work is either scrapped or rewelded. In order to avoid defects in welding, the blacksmith must always scrupulously fulfil all conditions and operations in welding work. Below a few examples of making welded parts are described.

Example 1. Making chain links. It is required to make a chain of three links (Fig. 127, *a*). For this, three pieces of the required length from a rod of the proper grade of steel are first cut off with a chisel.

Each piece of steel is heated and upset separately (Fig. 127, *b*). Then the centre of the rod (stock) is heated and bent. After bending, the ends to be welded are scarfed on the anvil as shown in Fig. 127, *c*. Then the scarfed ends are bent on the anvil horn so as to lap over each other (Fig. 127, *d*). These ends are heated to welding temperature, all scale is removed, and the bar is placed in the bottom swage with a semi-circular recess (Fig. 127, *e*). Then the ring is covered with a top swage of a similar shape, and the ends of the link welded together by striking the top swage. The weld joint must be then hammered and finished on the anvil horn.

To make a chain of three links, two links are first welded and finished as described above, and then joined together by the third link (Fig. 127, *f*) which is welded and finished in the same way as the first two. If it is required to make a chain several metres long, several sections of three links each must be first made, and then all the sections joined together to form a chain of the required length. All links must be of the same shape and dimensions.

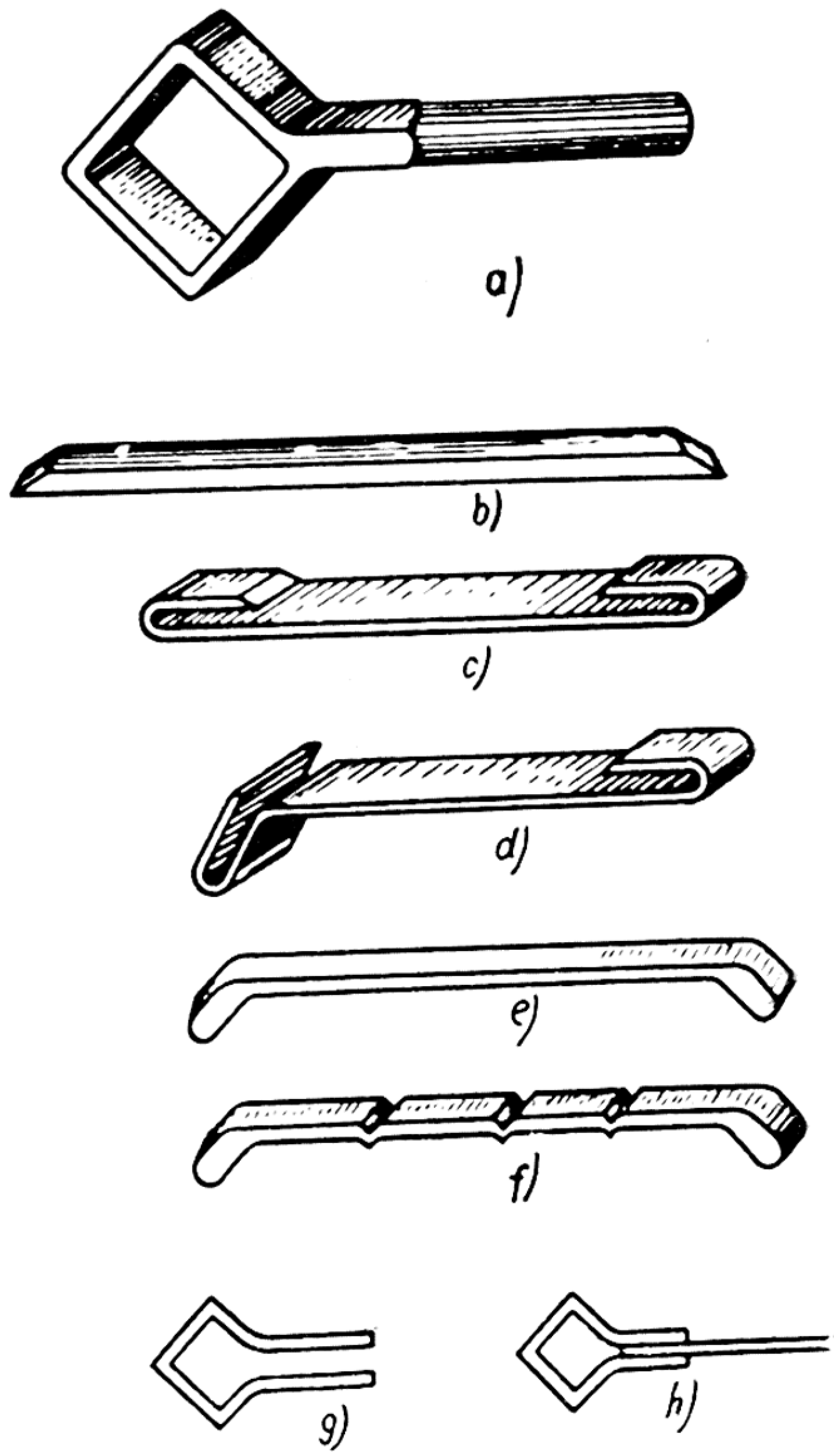


Fig. 128. Making a wrench by welding

Example 2. It is required to make a wrench for a two-inch nut (Fig. 128, *a*). This can be made from bar stock 50×12 mm in the following way.

A piece 400-410 mm long is cut from the bar; its ends are heated and pointed (Fig. 128, *b*); they are then heated to 700° C and doubled over for a length of 100 mm from each end, as shown in Fig. 128, *c*; then each double end is bent in turn, as shown in Fig. 128, *d*; one end so bent is heated to welding temperature and welded; this operation is repeated for the opposite end (Fig. 128, *e*). After the ends have been welded, they are hammered thoroughly and smoothed. To form the required corners the bar is fullered in three places as shown in Fig. 128, *f*, and bent to shape as shown in Fig. 128, *g*; then, after the handle has been inserted between the ends, they are all welded together,

as shown in Fig. 128, *h*. Then the wrench is straightened and finished to the required dimensions.

Example 3. It is required to make an axe-head (Fig. 129, *a*), with a blade of tool steel and body of low-carbon steel. A bar 60×35 mm is used. The axe-head is made in the following order:

The required length is measured and cut off from the bar. The cut-off piece is heated and drawn-out as shown in Fig. 129, *b*. Then the stock is fullered and bent as shown in Fig. 129, *c*, *d*.

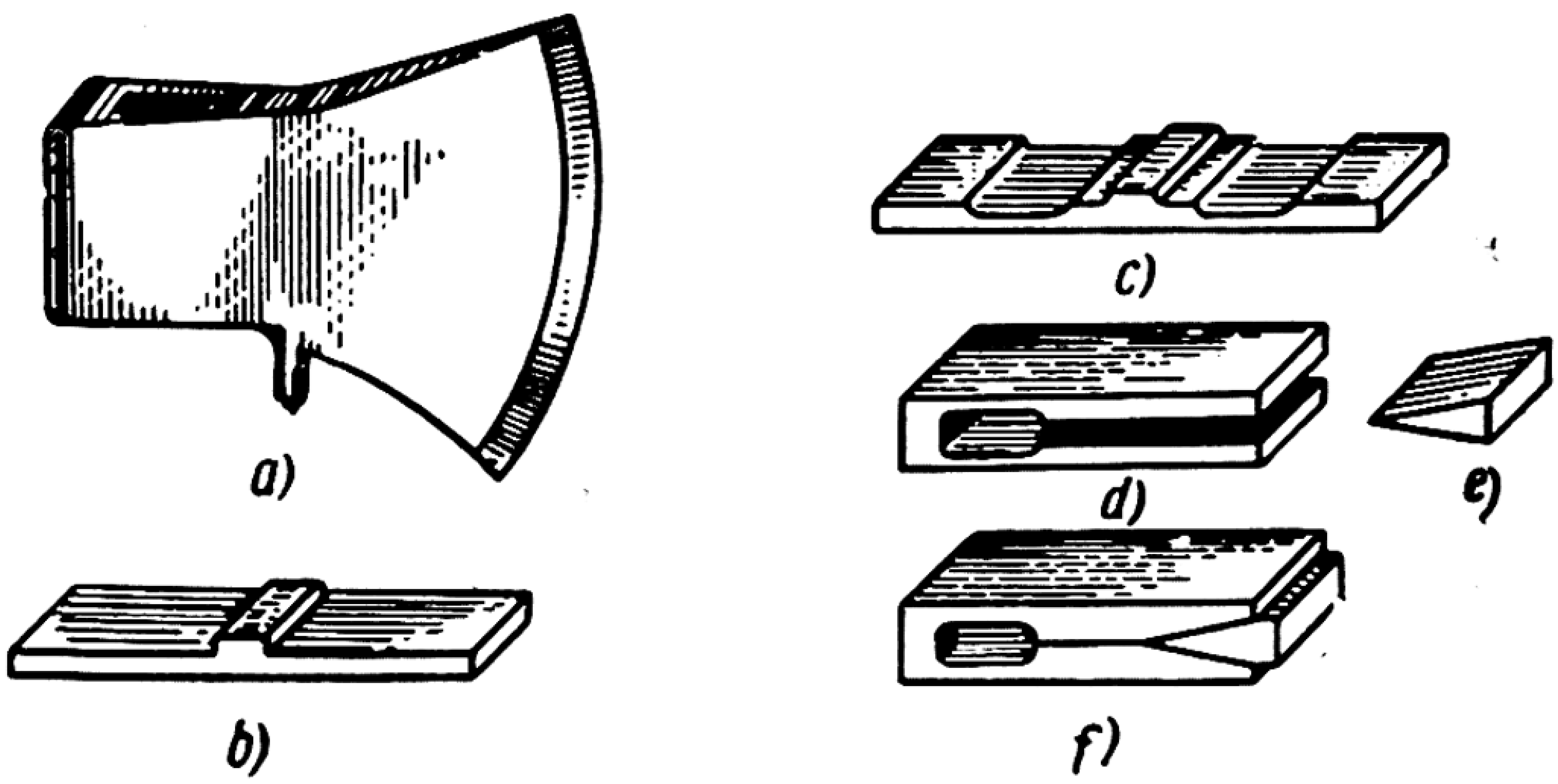


Fig. 129. Making an axe-head

A wedge-shaped piece of tool steel is prepared by hammering as shown in Fig. 129, *e*; its width should be equal to that of the blade of the axe-head. Then this wedge is inserted and fitted into the principal low-carbon steel forging (see Fig. 129, *d*), as shown in Fig. 129, *f*, after this the work is heated to welding temperature and welded. This done, the axe-head is hammered and finished.

EXAMPLES OF MAKING PARTS BY HAND FORGING

We now know how to forge by hand. Now let us discuss a few practical examples of making various forgings.

The Technological Process of Making a Bolt. It is required to forge a hexagonal-headed bolt according to drawing (Fig. 130), out of carbon steel stock, 25 mm in diameter; length of stock is 280 mm.

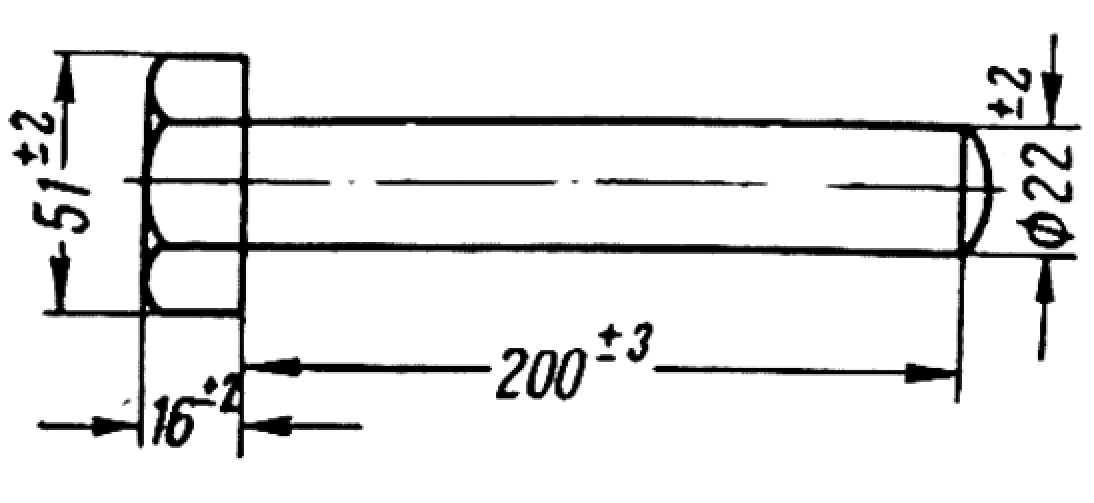


Fig. 130. Hexagonal-headed bolt

Bolts can be made by various methods, but the simplest and most common method is as follows: a bar of the same diameter as the bolt required, and slightly longer than its required length, is heated at

Chart 1

Bolt Process Chart

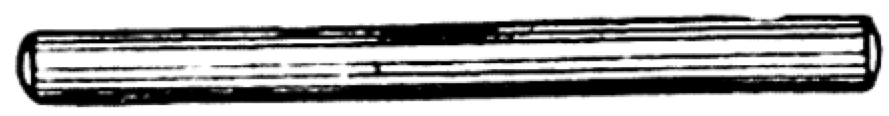
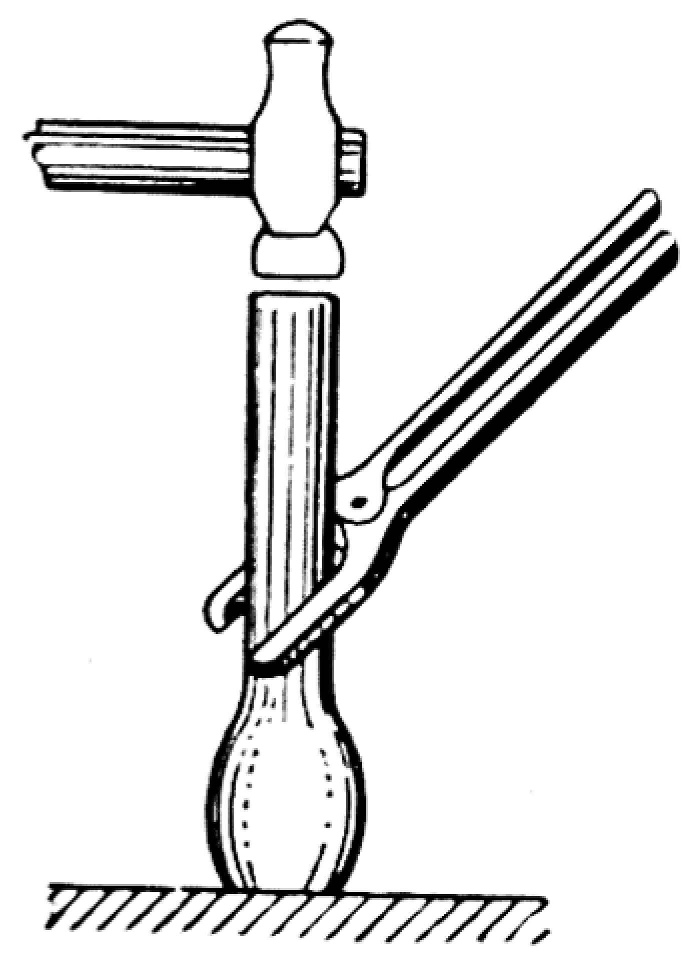
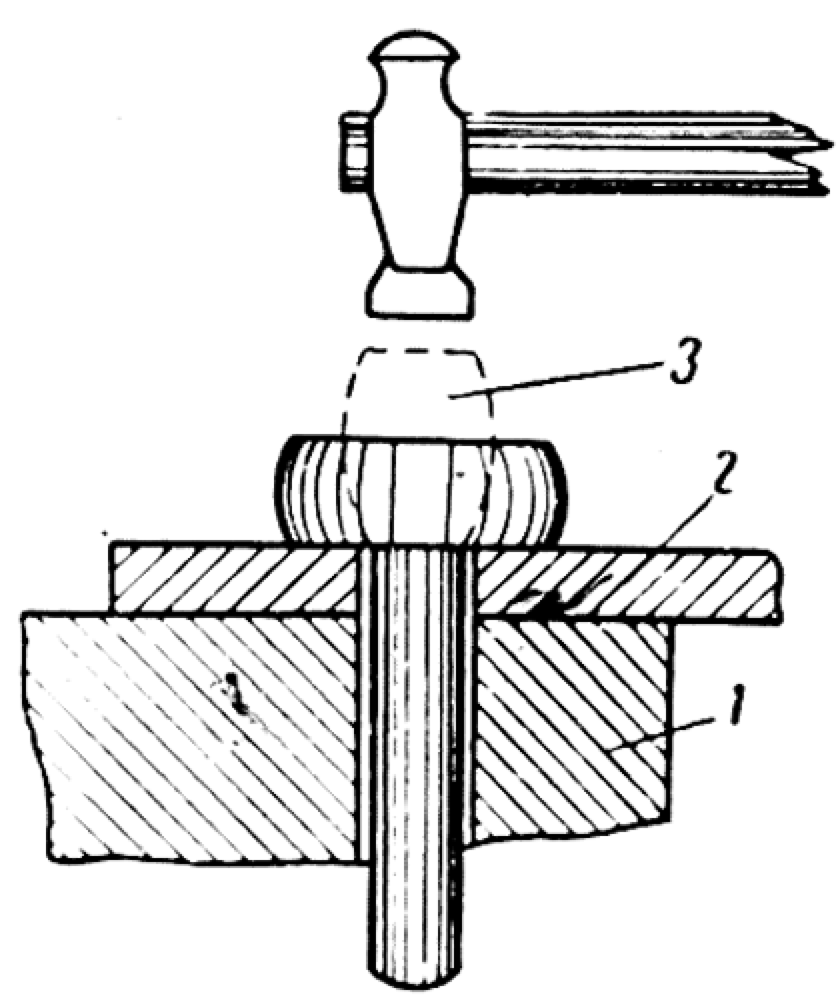
No	Description of pass and elements of operations	Equipment and tools required	Sketch of Pass
1	Take a 25 mm diameter bar and place it in hearth	Hearth tools	
2	Take hot stock out of hearth, place on anvil, measure 280 mm from one end of stock and cut off with hot set	Anvil, sledge-hammer, tongs, hot set and steel rule	
3	Heat one end of stock to length of 90 mm	Hearth, hearth tools, tongs	
4	Grip stock heated at one end with tongs, place it vertically on anvil and upset heated part with sledge-hammer	Anvil, tongs, hand hammer, sledge-hammer	
5	Place cylindrical part *3* of stock in bolt-header *2*. Place stock on anvil *1* so that shank of bolt passes through hardie-hole in anvil, and spread (upset) head of bolt with hand hammer	Bolt-header, anvil, hand hammer	

Chart 1 (continued)

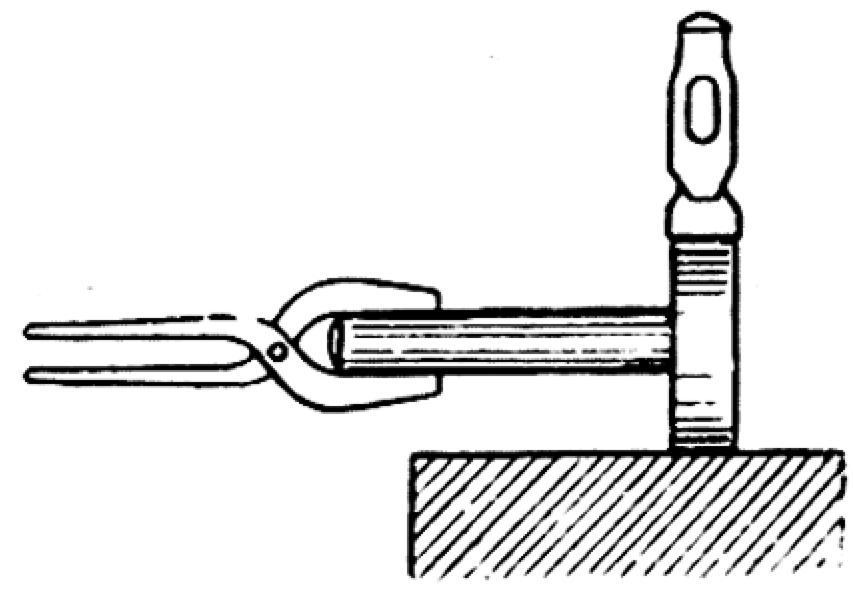
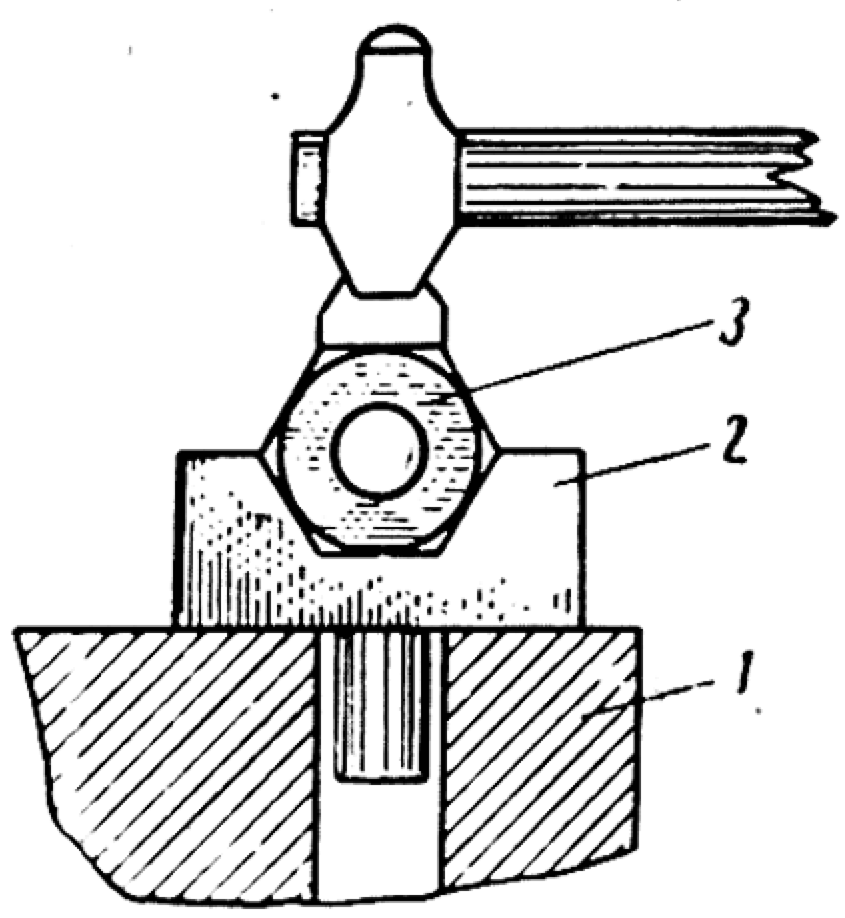
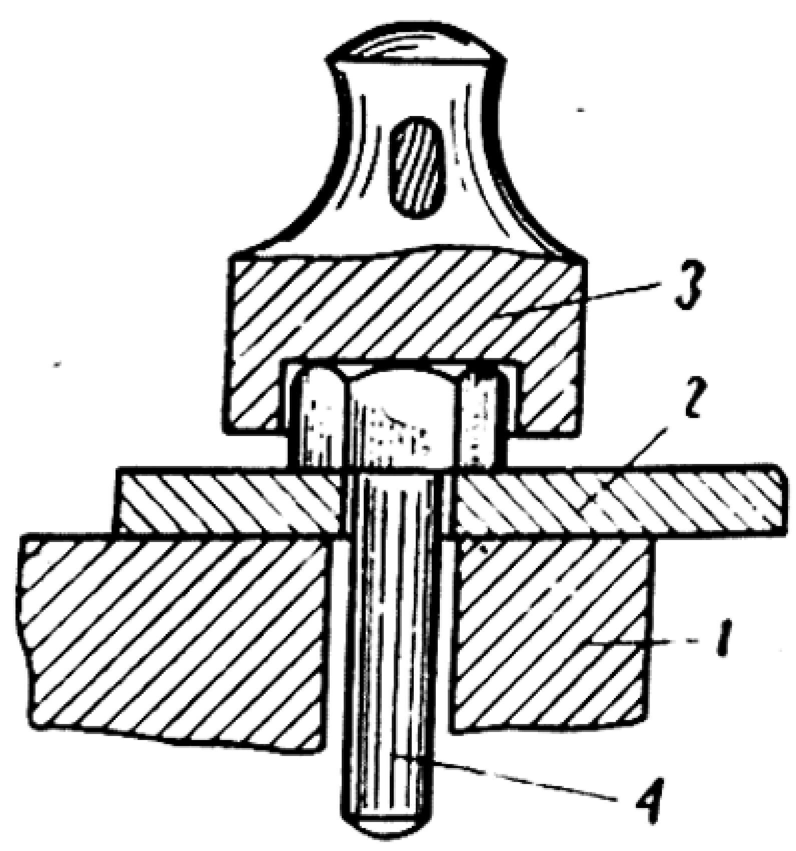
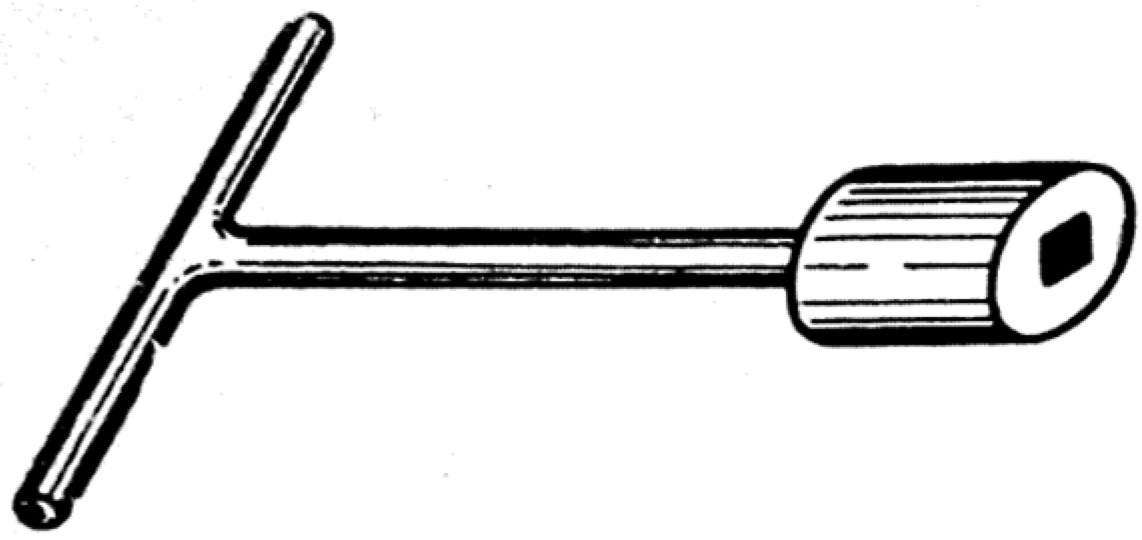
No	Description of pass and elements of operations	Equipment and tools required	Sketch of pass
6	Withdraw bolt from bolt-header and round bolt head on anvil face with hand hammer	Anvil, hand hammer, tongs	
7	Heat bolt head in hearth	Hearth, tongs	
8	Insert bottom swage *2* of required hexagonal bolt head dimensions in hardie-hole *1* of anvil; remove stock *3* from hearth, give it required hexagonal form in bottom swage *2*	Anvil, bottom swage, tongs, hand hammer	
9	Insert shank *4* of bolt in bolt header *2*, place stock on anvil *1* so that its shank passes through hardie-hole in anvil. Place smoother *3* on bolt head and, by striking smoother with hand hammer, make top of bolt head spherical in shape	Anvil, bolt-header, smoother, hand hammer, tongs	
10	Straighten shank of bolt on face of anvil. Check length of shank. If it is more than 200 mm long, heat end and cut off surplus with hot set	Anvil, hand hammer, tongs, hot set	

Chart 2

Socket Wrench Process Chart



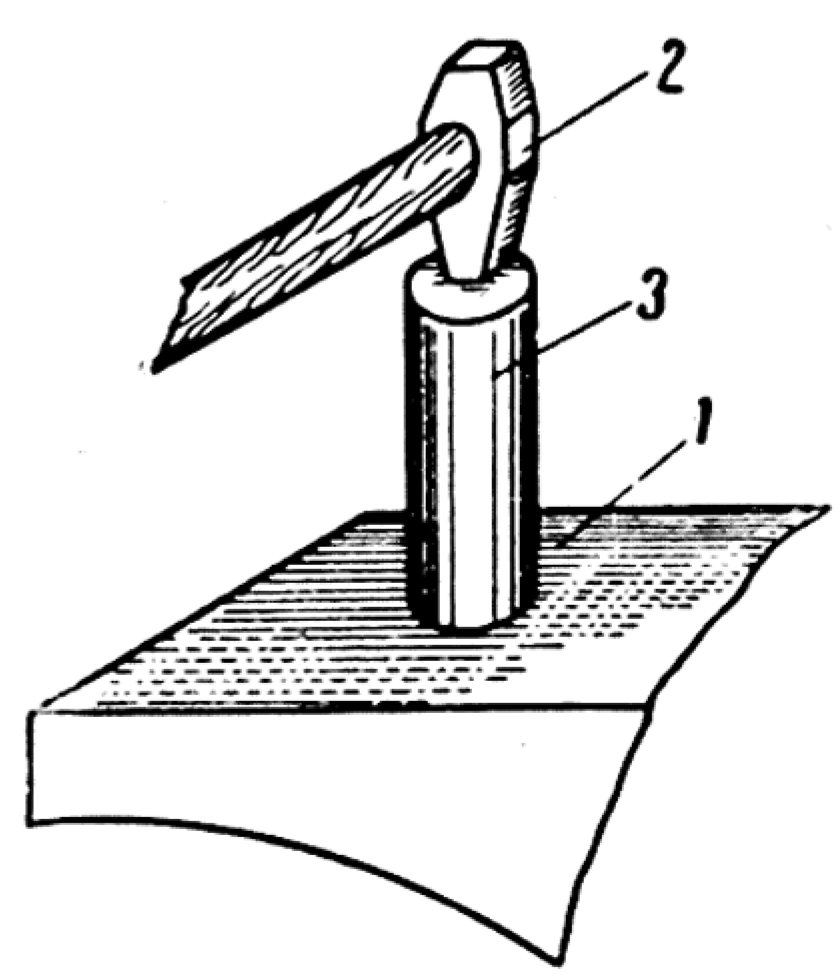
No	Description of pass and elements of operations	Equipment and tools required	Sketch of pass
1	Heat one end of bar in hearth	Hearth, hearth tools	
2	Remove bar from hearth and place on anvil, measure off required length of stock and cut off with hot set and anvil cutter	Anvil, anvil cutter, hot set, sledge-hammer, folding rule	
3	Heat one end of stock to length of 100-120 mm in hearth to 1200-1250°C	Hearth, hearth tools, tongs	
4	Remove stock *3* from hearth, place its cold end upright on anvil *1*, drive square punch *2* to required depth in hot end of stock to form socket hole	Anvil, tongs, square punch, sledge-hammer	

Chart 2 (continued)

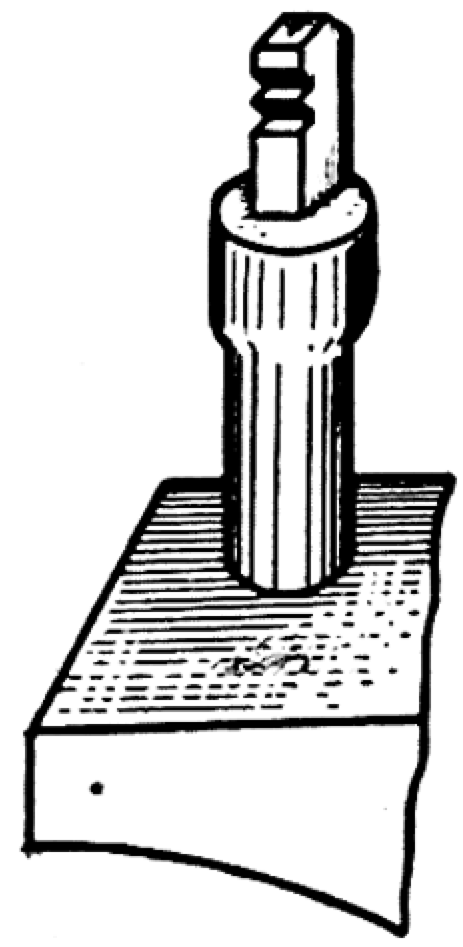
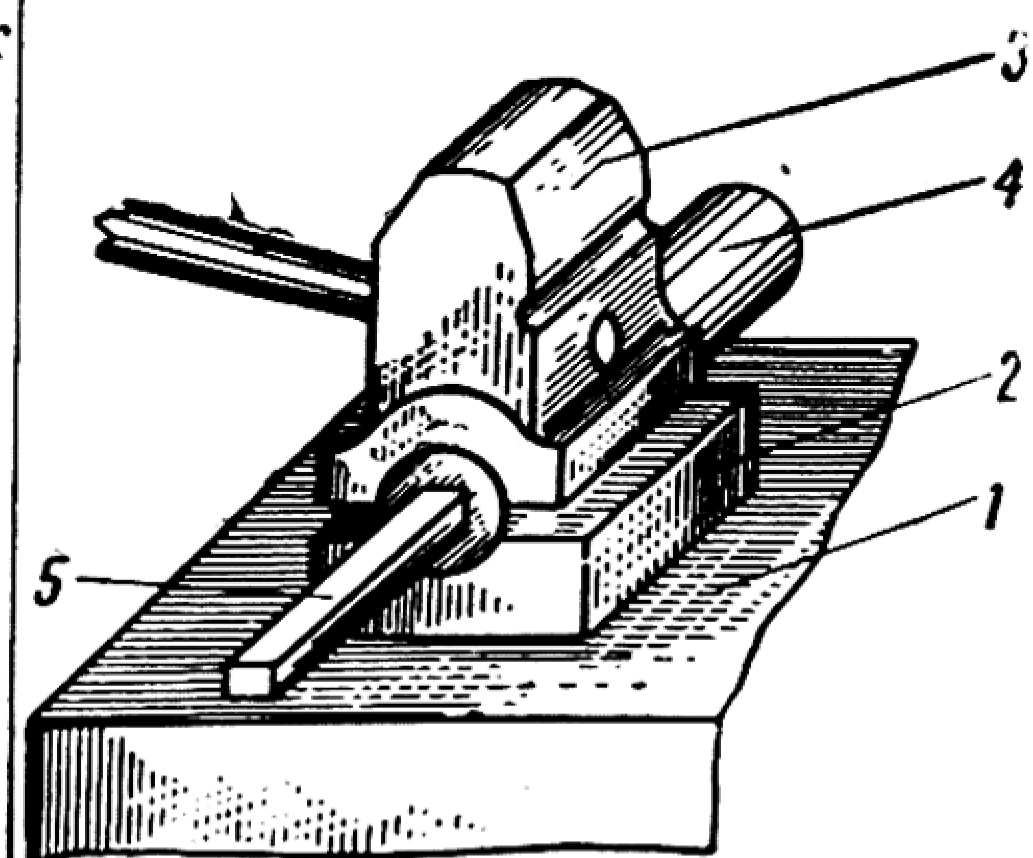
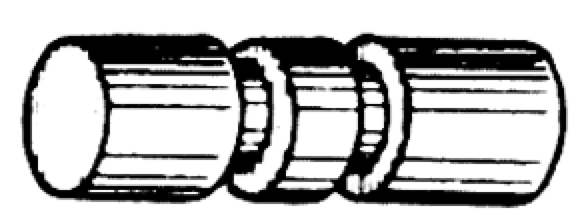
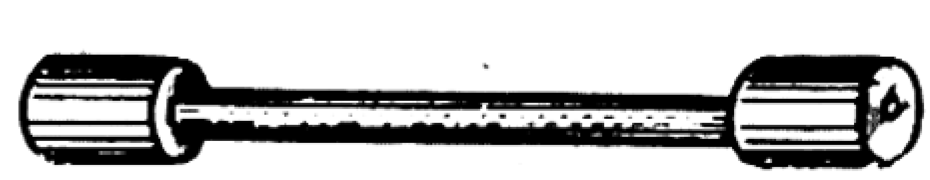
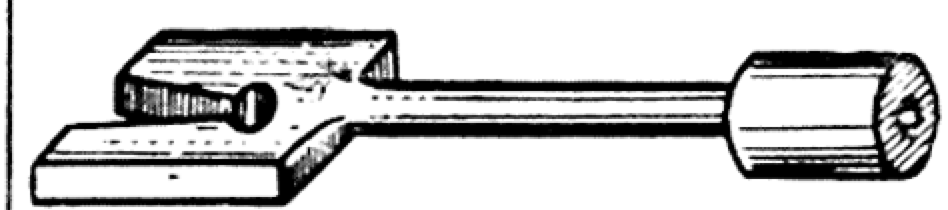
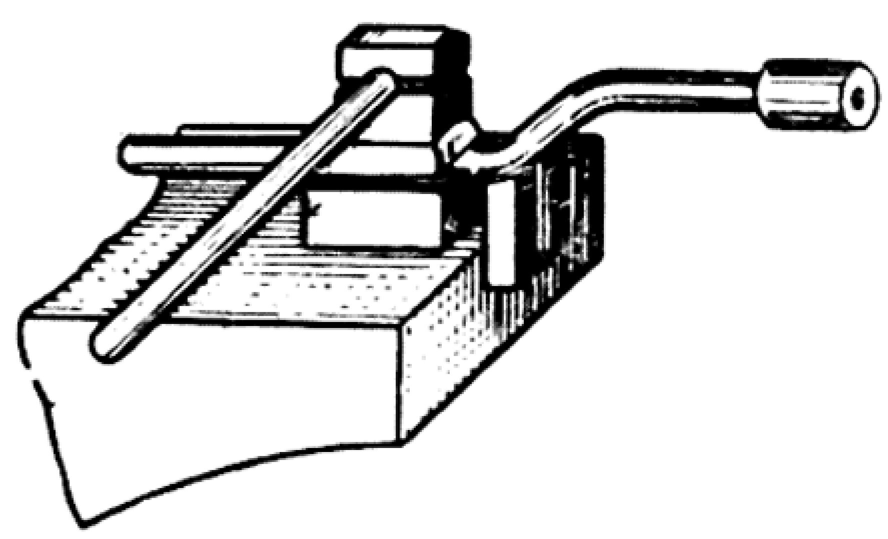
No	Description of pass and elements of operations	Equipment and tools required	Sketch of pass
5	Drive square mandrel in square hole to make proper shape for wrench	Anvil, tongs, square mandrel, sledge-hammer, hand hammer	
6	Swage end of stock *4* with hole; after swaging, withdraw mandrel *5* from socket hole	Anvil *1*, tongs, bottom swage *2*, top swage *3*, hand hammer and sledge-hammer	
7	Heat stock along its entire length	Hearth, hearth tools	
8	Fuller bar as shown in sketch	Anvil, hot set, bottom swage, sledge hammer, hand hammer	
9	Draw out centre of bar, hammering first of all to square cross-section, then to octagonal and then to round cross-section; swage drawn-out part in half-round faced smoothers to dimensions given in drawing	Anvil, tongs, fuller top and bottom swages, sledge-hammer, hand hammer, calipers, folding rule	

Chart 2 (continued)

No	Description of pass and elements of operations	Equipment and tools required	Sketch of pass
10	Heat second end of stock in hearth	Hearth, hearth tools, tongs	
11	Draw out and flatten end into bar for handle of socket wrench, punch a hole into it, and split with cape chisel as shown in sketch	Anvil, tongs, spreader, sledge-hammer, hand hammer, cape chisel, punch	
12	Heat split end of stock in hearth	Hearth, hearth tools	
13	Bend shank of socket wrench as shown in sketch (this makes it possible for blacksmith to draw out ends of cross-bar handle); draw out one of split ends by hammering to square, octagonal and round cross-sections in succession; swage and draw out to dimensions indicated in drawing	Anvil, tongs, sledge-hammer, top and bottom swages, calipers, folding rule	
14	Heat opposite split end of stock in hearth	Hearth, hearth tools, tongs	
15	Draw out heated end to dimensions indicated in drawing, in the same way as first end	Anvil, tongs, sledge-hammer, top and bottom swages, calipers, folding rule	
16	Straighten forging on anvil, check forging dimensions against drawing; if necessary, cut off surplus length of handles and swage ends of socket-wrench handles	Anvil, hand hammer, tongs, half-round smoothers, folding rule, hot set, calipers	

one end, and placed upright with its cold end on the anvil. Its heated end is then struck repeatedly with the sledge-hammer. The heated end will become thicker (be upset) as a result of these blows, thereby forming the head of the bolt. The upset head is then worked in corresponding devices, and given its necessary shape (square, hexagon, etc.) in bolt-headers.

The second method consists in taking a piece of stock of the same cross-section as the required bolt head, and drawing it out to the required length and cross-section (diameter).

Process Chart 1 describes the various operations and passes of the technological process of making a bolt; process Chart 2—the technological process of making a socket wrench.

CHAPTER VII

THE INFLUENCE OF DEFORMATION ON FORGINGS AND THE CALCULATION OF FORGINGS

PLASTIC DEFORMATION

By the *deformation* of a body is understood alteration of its shape under the action of external or internal forces. If, on the removal of these forces, the body resumes its initial shape, this deformation is called elastic (reversible) deformation. If, however, the body fails to resume its original shape after the removal of the forces acting on it, the deformation will be what is called plastic, or permanent, deformation. When subjected to plastic deformation, a body should not display signs of rupture, i. e., should have neither internal nor external cracks.

Forging is based on *plastic deformation*, during which the forged metal, under the blows of a hammer or the pressure of a press, changes its shape without breaking the continuity of the metal, i. e., without developing any cracks. After plastic deformation (forging) the volume of a given piece of metal will remain unaltered, the only change being in the relative location of the particles of which the given metal consists.

During the process of working a piece of stock heated to forging temperature, the blacksmith, with the aid of hammer blows or the pressure of a press, and employing various tools, forces the metal to flow in required directions until the work attains its specified dimensions and shape. In order to ensure sound forgings with a minimum expense of time and energy, blacksmiths must be conversant with the principal laws of the flow of metals in a plastic state.

Let us consider how a piece of stock changes its shape under the action of the blows of the hammer dies for the case of plastic deformation during forging, or smith forging, as it is also called.

Under the blows of the hammer die, the height of the stock is reduced, its length and width simultaneously increasing. This is shown schematically in Fig. 131. The arrows indicate the direction of the flow of the particles of metal, squeezed out by the hammer dies. The volume of metal compressed between the ram or hammer dies is called the *deformation centre*. The ratio of the increased length to the increased width of a bar of metal, i. e., between the volume of

metal displaced along the length and width of the bar, will depend on the shape of the deformation centre.

The shape of the centre of deformation depends on the length l of the top die of the hammer, and on the width b of the bar. The longer

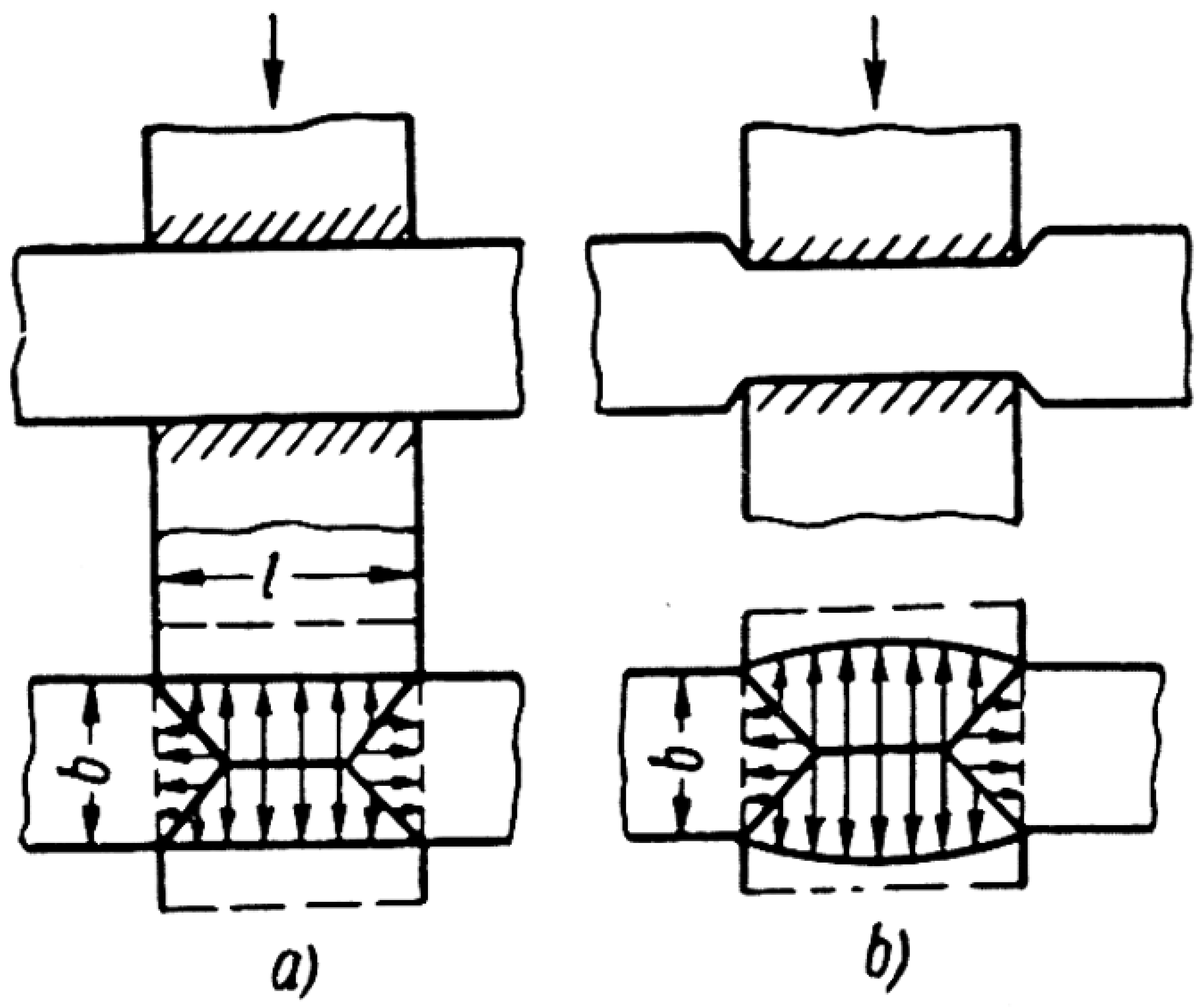


Fig. 131. Scheme of flow of metal: a) commencement of deformation; b) end of deformation

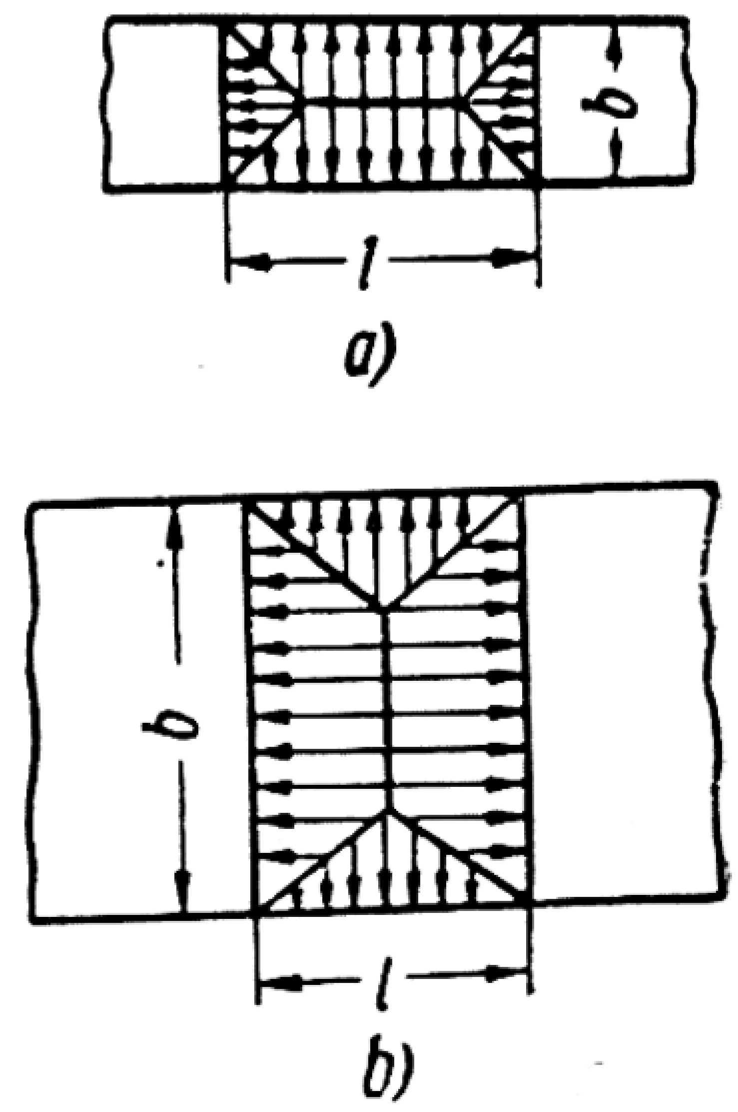


Fig. 132. Shape of deformation centre (plan)

and narrower the centre of deformation (Fig. 132,*a*), the greater will be the bar's increase in length and the less its increase in width. This flow of metal in length and width during forging is governed by the law of least resistance. According to this law, each particle of metal subjected to the pressure of a hammer dies, strives to liberate itself from the hammer dies by the shortest route. With a long centre of deformation, the greater part of the metal will be displaced longitudinally; and blacksmiths make skilful use of this law.

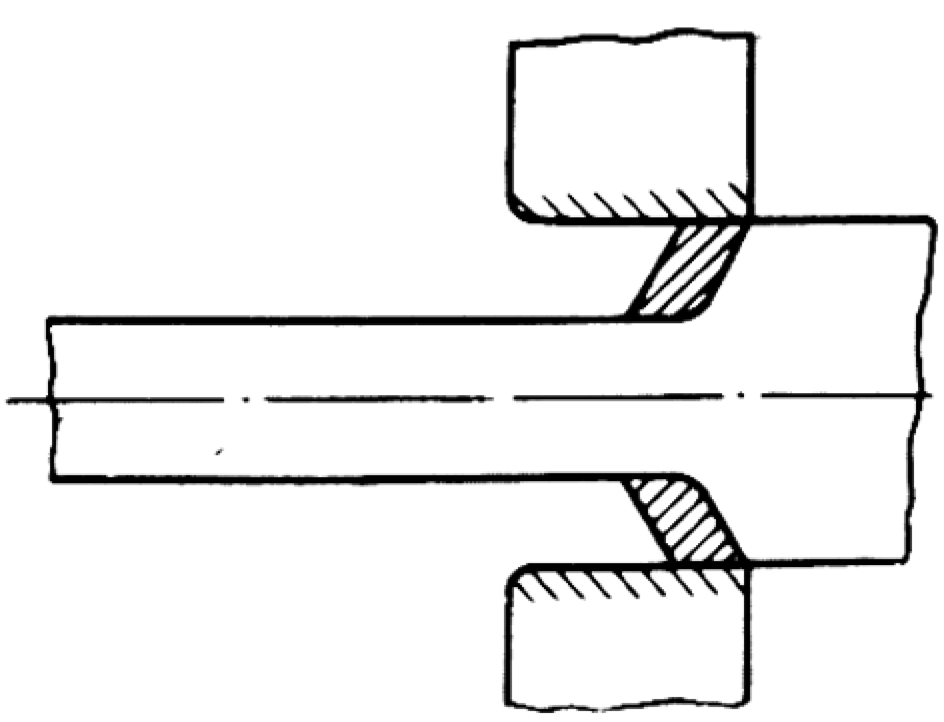


Fig. 133. Drawing-out (reducing) a piece of stock with short grips

Hammer dies and anvils or top and bottom dies with narrow faces should be employed for drawing-out metals, or the drawing-out effected with short grips, as shown in Fig. 133. Also the fact should be taken into consideration that the shallower the depth of deformation is, the less thoroughly will the metal be forged through its cross-section. The width of the ram head (top hammer die) is generally determined by practical experience. If the work is to be drawn out with short grips, then, in order to ensure a smooth surface, the stock

must be moved forward, i. e., moved across the anvil or bottom die for a definite part of the width of the top die of the hammer.

We have discussed the effect of the *law of least resistance* on metal for the case of the plastic deformation of a piece of work forged in length and width between a hammer and an anvil (or dies). However, the deformation of a piece of stock is similarly unequal along its height. For instance, when *upsetting a short solid cylinder*, the metal will flow more intensively at its centre than at the areas contacting the top and bottom dies (Fig. 134, *a*). Moreover, during upsetting, the stock will become barrel-shaped for two reasons: 1) the friction between the surfaces of the stock and the faces of the top and bottom dies of the hammer; 2) the cooling action of the hammer dies on the metal being forged.

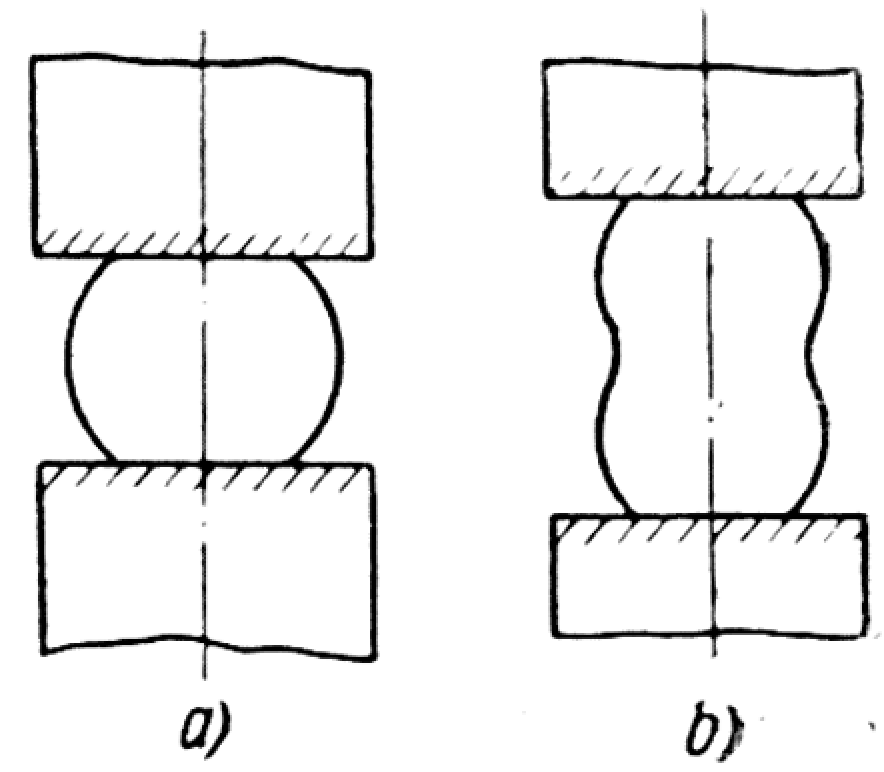


Fig. 134. Uneven deformation of a piece of stock along its height

Owing to the fact that the faces of the hammer dies can never be perfectly smooth, friction is always generated between the metal being forged and the surfaces of the hammer and anvil or dies where they contact the stock. Because of this, the particles of metal contacting these surfaces will flow more slowly than those located at the centre of the stock. Hence the following conclusion may be drawn: the smoother the surface of the hammer and anvil or dies, the less will be the friction between them and the metal and, consequently, the less the metal will buckle at its centre. In order to reduce friction of the metal, the faces of the hammers and anvils or dies must be highly polished and lubricated with a special grease; even then, this buckling can never be completely eliminated—it can only be reduced to a certain extent.

The cooling effect of the dies, or of the hammer and anvil, on the surface of the work being forged also influences the flow of metal. Cold hammers and anvils absorb heat from the surface of the stock being forged; consequently, the temperature at the surface of the stock will be lower than at its centre; it follows, therefore, that the particles at the surface of the stock will be less mobile than those at its centre. And this increases the bulging of the work when forged.

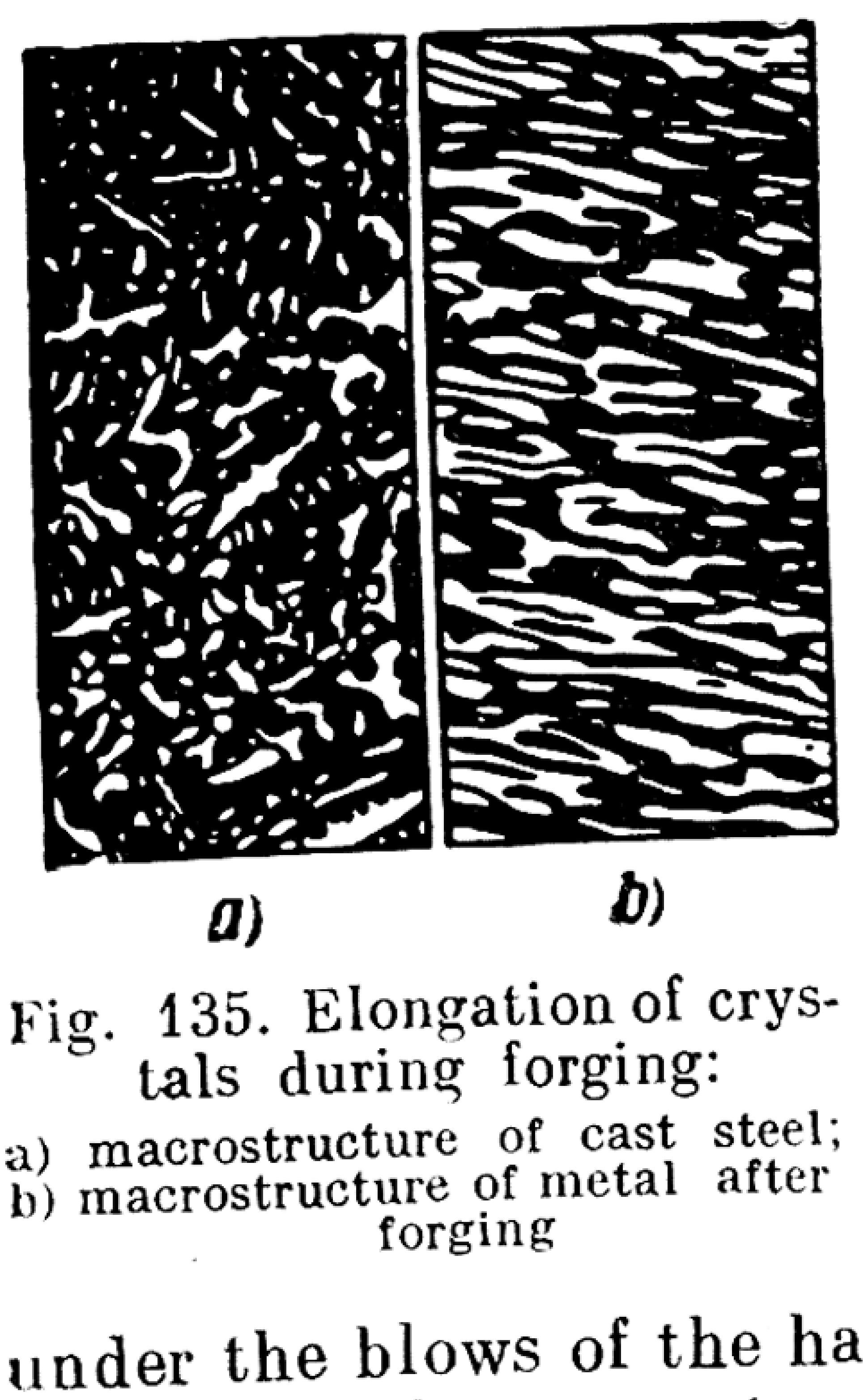
When *upsetting long work*, i. e., stock, the length of which is 2.5 times more than its diameter or the distance between its opposite sides, a double-barrel deformation can be observed (Fig. 134, *b*). This can be explained by the fact that, depending on the degree of reduction in length of the stock and the speed of application of force to the metal, deformation is diffused throughout the section of the hammered stock to a definite depth, beginning from the

face of the ram head and the anvil or the faces of the top and bottom dies of the hammer; in this case the metal at the centre of the work is not subject to deformation.

The greater the degree of deformation, and the lower its speed, the deeper will the deformation penetrate into the hammered (forged) metal. For this reason, the capacity of a hammer, or the pressure of the press, must correspond to the cross-section of the work being forged in order to ensure that the metal is properly worked.

THE EFFECT OF HAMMERING ON THE STRUCTURE AND MECHANICAL PROPERTIES OF A METAL

When a metal is hammered or forged, its macrostructure and mechanical properties undergo changes. These depend on the following factors: 1) the temperature conditions of the forging process; 2) the degree of reduction of the cross-sectional area; 3) the method of forging employed; 4) the chemical composition of the metal.



a) b)

Fig. 135. Elongation of crystals during forging:
a) macrostructure of cast steel; b) macrostructure of metal after forging

When forged, the structure of the metal changes in two diametrically-opposite directions. The structure of an ingot when hammered becomes fibrous. The formation of a fibrous structure is characterised by the fact that, when an ingot of steel, for instance, is forged, the liquation zones, gas bubbles, slag inclusions, etc., and, at low temperatures, the grains of steel (dendrites), are drawn out in the direction in which the metal flows. The structure of the ingot changes from a coarse-grained to a fine-grained, because the crystals are crushed under the blows of the hammer or the pressure of the press. Fig. 135 illustrates the macrostructure of cast and forged metal.

Other structural changes of the metal also take place when rolled metal is forged. The grains change to a lesser degree, as they have already been crushed to a certain extent during the rolling process. Forging, as distinguished from rolling, results in a greater degree of *disorientation* of the fibre of the metal. For this reason, the mechanical properties of forged metal are higher than those of rolled metal.

As a result of forging at high temperatures, the grains of the metal grow simultaneously with the change in the crystals. This is due to the creation of conditions which aid the combination of tiny grains

to form larger grains. This phenomenon of grain growth, i. e., of the combination of small grains to form larger grains, is called *collective recrystallisation*. The higher the forging temperature, the greater will be the growth of the grain.

Collective recrystallisation tends to lower the resistance of a metal to deformation. Consequently, metals should be forged at temperatures which foster grain growth (recrystallisation), and be comleted at temperatures at which recrystallisation no longer occurs. This will ensure fine-grained forgings possessing high mechanical properties.

From the foregoing, it can be concluded that the structure of a metal, and, at the same time, the mechanical properties of a forging will depend on the degree to which its grains have been crushed as a result of their deformation and recrystallisation.

The structure of a metal likewise depends on the reduction factor, i. e., on the reduction of its cross-sectional area (during drawing). By the *reduction factor* is understood the ratio of the cross-sectional area of a piece of stock to that of the finished forging. The greater the reduction factor (i. e., the degree of drawing) the finer will be the grain and the more pronounced will be the band structure of the forging. Ingots can be reduced to a greater degree than rolled stock. The minimum reduction factor for forging carbon steel (flat parts) is 3.0; for flanges and shoulders — 1.75; for alloy steels (flat parts) — 2.0; for flanges and shoulders of alloy steels — 1.5. The reduction factor for forgings from ingots is accepted as 3-4 (flat parts) and 1.5-1.75, for flanges and shoulders.

When an ingot is forged, its large crystals are destroyed and the metal is made denser (compressed); this results in the elimination of cavities, welding bubbles, etc., in the ingot, whereas in rolled sections the crystal-like structure of the metal is destroyed (crushed) during the rolling process. The higher the heating temperature of the metal before forging, the greater the reduction factor will be.

If a piece of work has been reduced in forging to a greater degree than normal, the mechanical properties of the metal will be increased along the direction of drawing, and reduced in the transverse direction.

Example. Determine the reduction factor of a forging when drawn out (reduced) from 300×300 mm to 200×200 mm.

Solution. Cross-sectional area of forging

$$A_{forg}=20\times20=400 \text{ cm}^2.$$

Cross-sectional area of stock

$$A_{stock}=30\times30=900 \text{ cm}^2.$$

$$\text{Reduction factor}=\frac{A_{stock}}{A_{forg}}=\frac{900}{400}=2.25.$$

The mechanical properties of forgings also depend on the method of their production. The same piece of work can be forged by different methods; moreover, the forgings obtained by these methods can likewise possess different mechanical properties. It is always necessary to try to make forgings without cutting across the fibre of the metal.

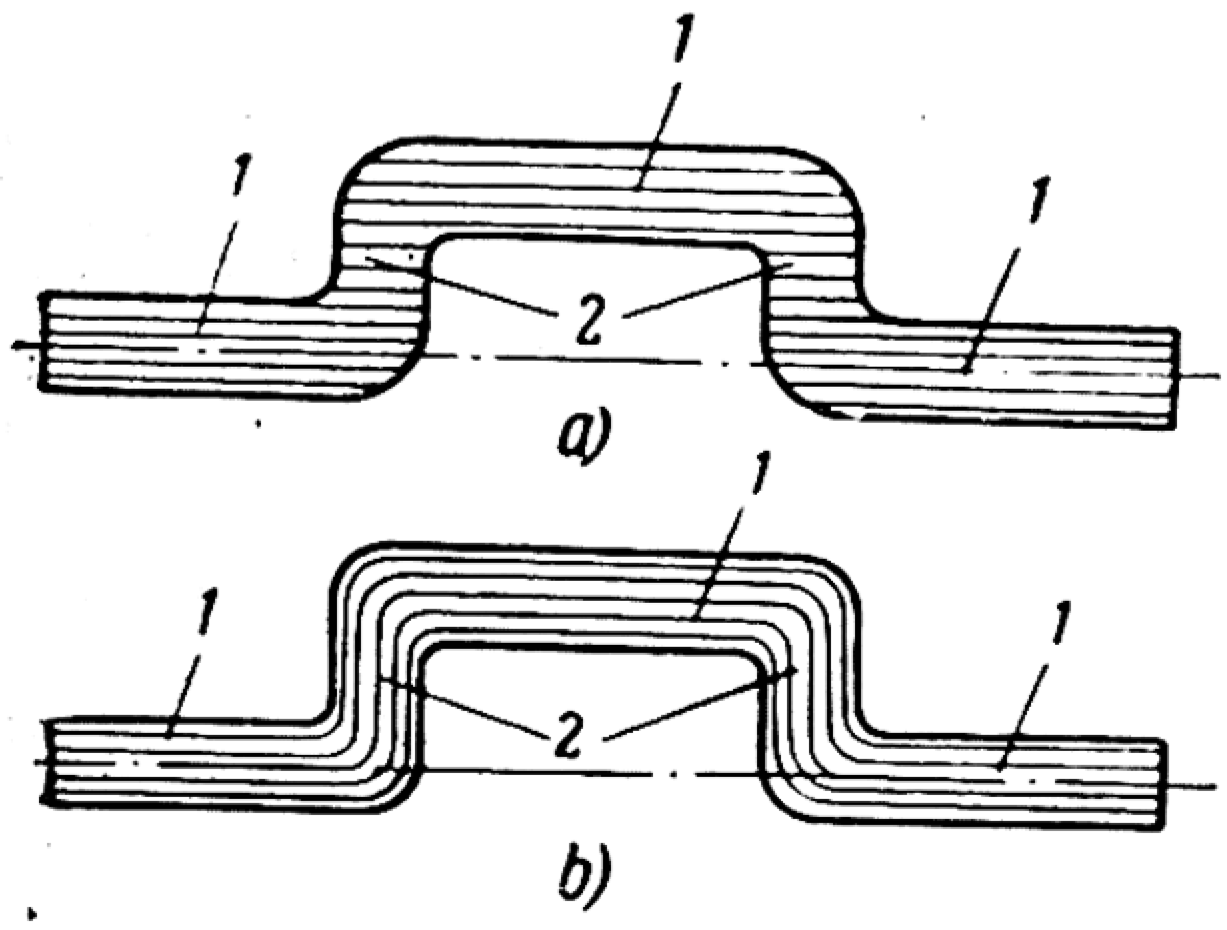


Fig. 136. Two methods of forging a crankshaft:
a) by cutting out cranks; b) by bending

Let us take two methods of making a crankshaft: Method 1 (Fig. 136,*a*) by cutting out the cranks, and Method 2 (Fig. 136,*b*) by bending. The mechanical properties of the crankshaft bent will be the same in all its sections (in journals *1* and cranks *2*), as the fibre of the metal has not been interrupted and continues along the entire length of the shaft. The fibre of the metal of the crankshaft made by the first method has, however, been interrupted; and for this reason the mechanical properties of this shaft will be poorer than those of the crankshaft made by the bending process.

ALLOWANCES FOR MACHINING FORGINGS, FORGING TOLERANCES AND ALLOWANCES

Forgings produced in forge shops are classified as rough and finished forgings. *Rough* forgings are subjected to subsequent machining; *finished* forgings are however not subjected to any further machining.

Before a rough forging can be produced, a forging drawing, based on the dimensions of the finished part or of the machined rough forging, must be made. The dimensions of the forging, i. e., the *nominal* forging dimensions, are obtained by adding the machining allowances to each dimension of the finished part. *Allowances* are the amounts of stock provided over and above the nominal dimensions of the finished part. The amount of the allowance must be such as to ensure the specified dimensions and surface finish of the part.

No matter how carefully the blacksmith may do his work, the dimensions of the forging will always be greater or less than its nominal dimensions. For this reason, in order to minimise the variation from the nominal forging dimensions, forging drawings always specify the permissible variations, or tolerances, thereby limiting the blacksmith's inaccuracy. Consequently, the *tolerance* for any dimension of a forging is the difference between its maximum and min-

imum permissible dimensions. The permissible variation from the nominal dimension of a forging by which a given dimension can be increased is called the upper tolerance; the *upper tolerance* is the difference between the maximum permissible dimension of a forging and its nominal dimension. The permissible variation of the dimension of a forging by which a given dimension can be decreased from its nominal dimension, is called the *lower tolerance*. In other words, the lower tolerance is the difference between the nominal dimension and the lower minimum dimension of the forging.

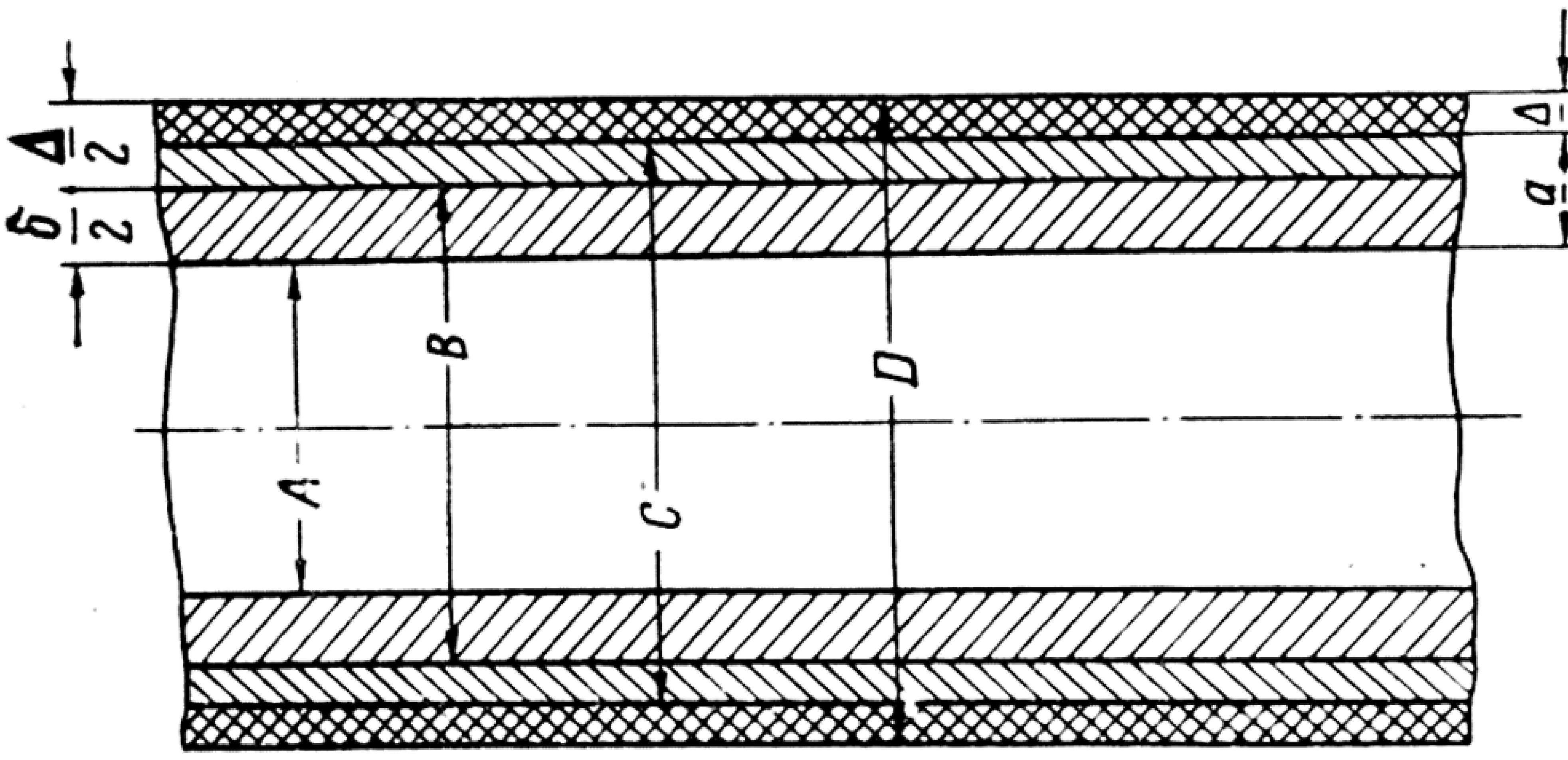


Fig. 137. Location of allowances and tolerances of external dimensions of a forged part

Machining allowances can be minimum, nominal or maximum, depending on the tolerances.

Fig. 137 illustrates the *diagram of the location of allowances and tolerances* for the external dimensions of a part,

where A — the nominal dimension of the part;
δ — the nominal allowance for dimension A;
B — the minimum permissible dimension of the forging, equal to $B=A+\delta$;
a — the nominal allowance for dimension A, equal to $\delta+\frac{\Delta}{2}$;
C — the nominal (calculated) dimension of the forging, equal to $A+a$;
Δ — the tolerance;
$\frac{\Delta}{2}$ — variations from the nominal dimension of the forging;
D — the maximum permissible dimension of forging, equal to:

$$B+\frac{\Delta}{2}=A+\delta+\Delta.$$

Example. The nominal dimension A (diameter) of a shaft is 200 mm; the allowance $a=15$ mm; tolerance $\Delta=\pm5$ mm. Determine the maximum and minimum permissible diameters of the shaft.

Solution. The nominal (calculated) dimension (c) of the forging will be:

$$B=200+15=215 \text{ mm.}$$

The maximum dimension D of the forging will be:

$$B+\frac{\Delta}{2}=(200+15)+5=220 \text{ mm.}$$

The minimum dimension B of the forging will be:

$$A+\delta, \text{ where } (\delta)=a-\frac{\Delta}{2}, \text{ or}$$
$$B=200+(15-5)=210 \text{ mm.}$$

Consequently, the forging will be considered as being acceptable if it is made with a maximum diameter of 220 mm and a minimum diameter of 210 mm.

Only forging tolerances are specified for finished forgings; no machining allowances are specified as finished forgings will not be subjected to machining. Every blacksmith must do his best to make the forgings with the minimum upper tolerances and allowances. The smaller the upper tolerance and the smaller the allowance, the less metal will be required for making the forging, and the less time will be needed for its machining. Consequently the work will be cheaper.

It must always be remembered that the upper variations of the forging dimensions are the maximum limits by which its dimensions may be increased. The maximum upper variations should never be increased; on the contrary, during the forging process, they should always be reduced as much as possible.

When making a drawing of a forging, it is often necessary to simplify its profile, leaving extra metal in the form of additional allowances at certain places. These additional forging *allowances* are simply increased allowances, which simplify the profile of a forging because of the impossibility or high cost of making the forging exactly conform to the profile of the finished work. These additional allowances increase the consumption of metal and the time needed for machining the forging.

Appendix 2 gives the allowances and tolerances specified in GOST 7829-55 for carbon and alloy-steel hammer forgings.

DRAWINGS OF FORGINGS

The drawing of any forging is always based on the designer's drawing of the finished part. The dimensions specified in the forging drawing are always increased by the amount of the allowance specified for machining its surface; in addition, the forging tolerances are also specified. In special cases, when making complicated work,

the profile of the forging is simplified with the aid of additional allowances.

The drawing of a forging is begun by drawing the *finished contour* of the part in thin lines; at the same time the basic finished dimensions are indicated. This done, the amounts of additional allowances are determined and, in conformity with tables, the machining allowances and tolerances for the nominal forging dimensions, depending on the type of forging, are specified. After this, the contours of the forging are drawn around the finished contour, in thick lines, and the forging dimensions and allowances written in. The nominal dimensions of the forging are written above the dimension lines, together with the forging tolerances, while the dimensions of the machined part are written in brackets under the dimension lines. If the forging is to be produced in a press, its nominal dimensions are rounded off to the nearest 5 or 0. This means that all forging dimensions ending in 3,4, 6, or 7, are rounded off to the nearest 5, while dimensions ending in 1, 2, 8, and 9 are rounded off to the nearest 0. For instance, forging dimensions of 282 and 288 mm will be rounded off to 280 and 290 mm respectively.

If a forging is to be made with a test specimen, i. e., with an additional allowance for a test specimen, the dimensions of this specimen are included in the drawing of the forging.

Some types of forgings include the following elements: a *collar*—a section of the forging, having a cross-section greater than the rest of the forging, and the length of which is equal to, or less than 0.3 D, where D—the diameter or length of the greatest side of the collar; *step*—a section of a forging with a smaller cross-section than that of the adjacent section of the forging; *shoulder*—a section of the forging, having a cross-section greater than that of its adjacent section; *neck*—a section of a forging having a diameter or side shorter than the diameter or side of the two sections adjacent to it.

It has already been learnt that allowances are specified for the nominal dimensions of a part. These allowances are calculated for machining the forging from two opposite sides, and must be sufficient to ensure the production of a good part after the forging has been machined. The amount of the allowance, tolerance, and additional allowances will depend on the type of a forging and the proportion of its dimensions. For this reason all forgings, depending on their profile and cross-section, are classified into 16 types, for the purpose of specifying allowances and tolerances. Fig. 138 gives *some types of forgings.*

Type 1 includes straight forgings of round and rectangular cross-section;

Type 2 includes stepped forgings of round cross-section;

Type 3 includes flanged forgings of round cross-section;

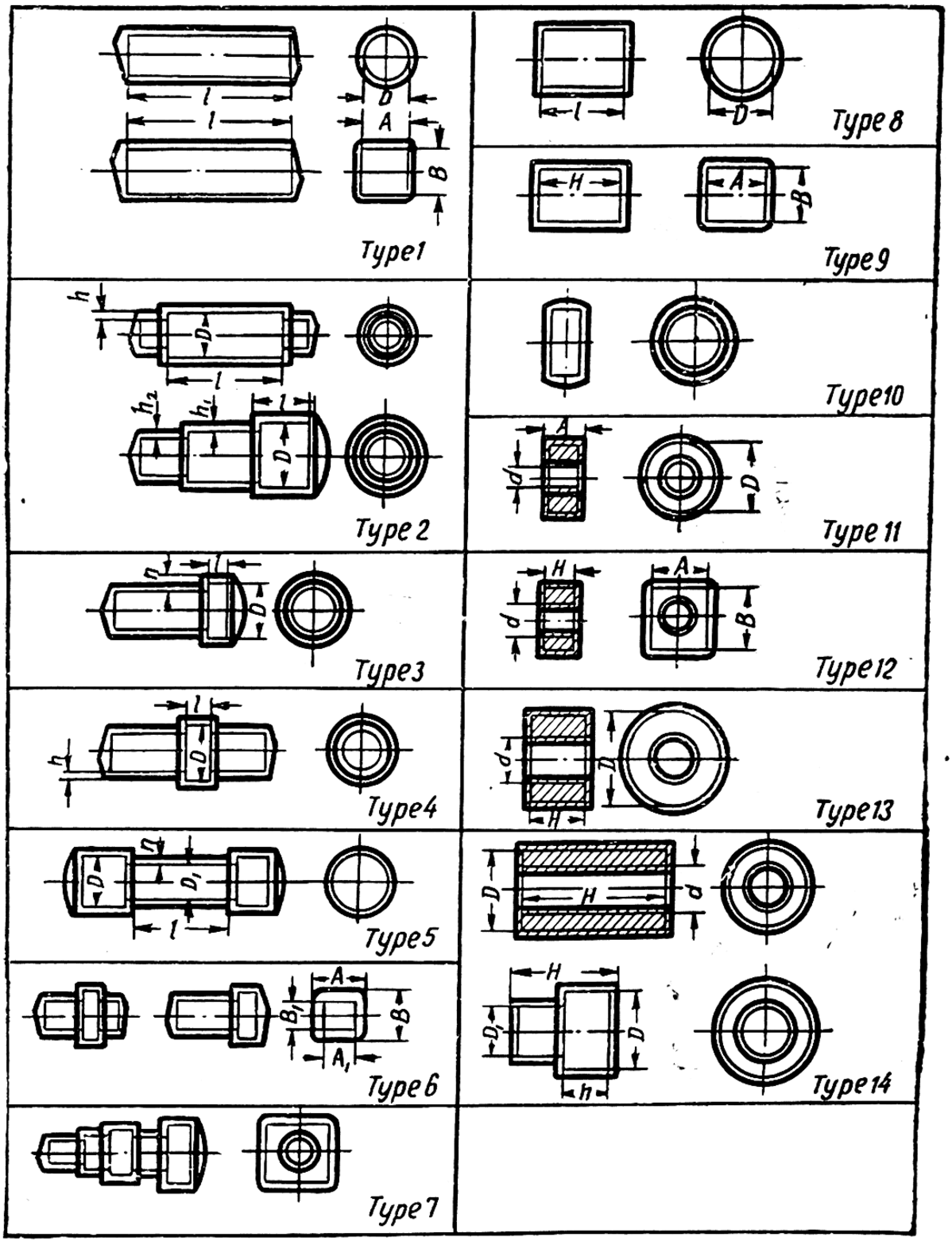


Fig. 138. Types of forgings

Type 4 includes collared forgings of round cross-section;
Type 5 includes necked forgings of round cross-section;
Type 6 includes stepped forgings of rectangular cross-section, similar to forgings of Type 2;
Type 7 includes stepped forgings of rectangular and round cross-section, with steps of various shapes and contours;

Types 8, 9, 10, 11, 12, 13 and 14 include cylinders, bars, cubes, plates, discs, holed discs, holed plates, rings, bushings, solid and hollow stepped bushings.

Below are given several examples of making drawings for forgings, and of calculating their allowances and tolerances.

Example 1. It is required to make a forging drawing of a gear blank (Fig. 139). The forging is of Type 11—a disc with a hole (see Fig. 138).

First of all, a scale drawing in thin lines is made of the contours of the gear blank (Fig. 140). Then, the allowances and tolerances for this type are determined (see Appendix 8). The data in this table refer to forgings having a shape in which $H \leqslant D$, and $d \leqslant 0.5\,D$. As can be seen from this table, the allowances a, b and c, as also the variation $\pm\frac{\Delta}{2}$ will depend on the outside diameter D and height H of the gear. In this case, for a gear with outside diameter D of 350 mm, and height H of 110 mm, the allowance and tolerance for diameter D will be $a=16\pm4$; the allowance and tolerance for internal diameter d will be $c=22\pm4$ mm, and the allowance and tolerance for its height H will be $b=13\pm4$ mm. Consequently, the dimensions of the forging will be: outside diameter $D_1=D+a=350+16=366$ mm; height of forging $H=H+b=110+13=123$ mm; and internal diameter $d_1=d-c=120-22=98$ mm. However, the forging dimensions of the hole will depend on the nominal diameter of the punch. In this case, d_1 will be 100 mm.

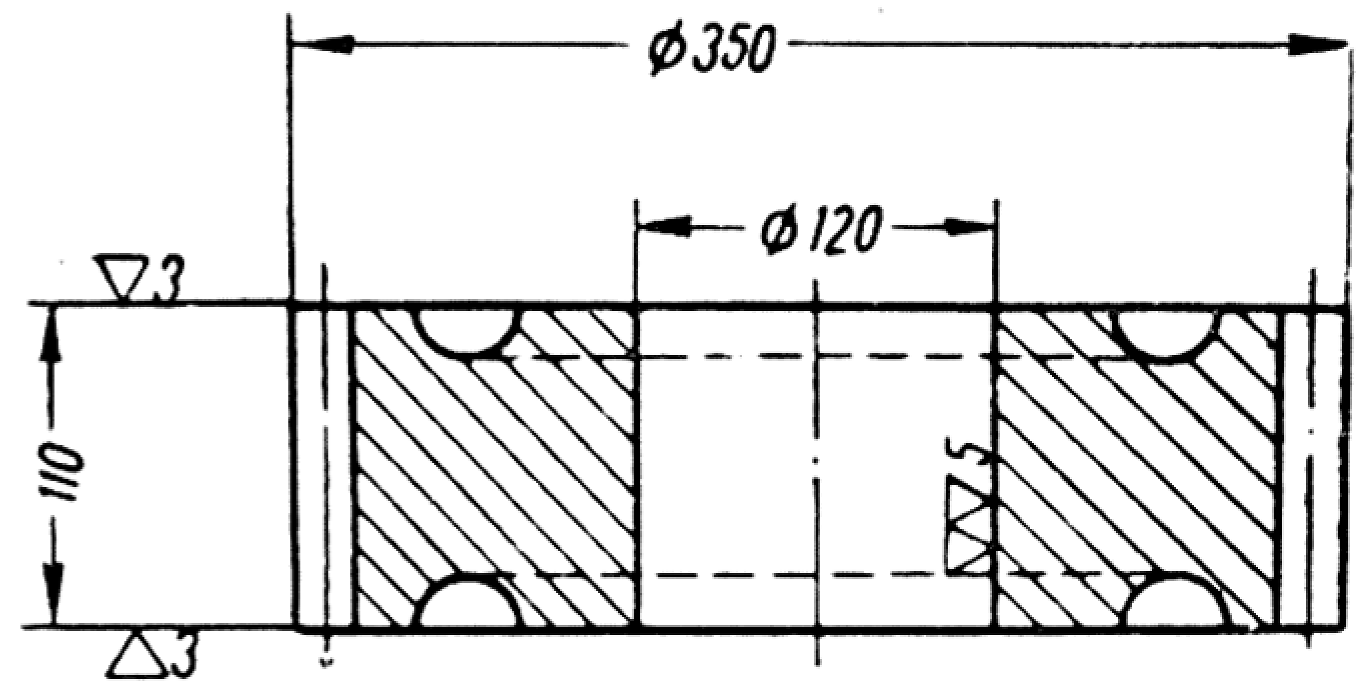


Fig. 139. Designer's drawing of a gear blank

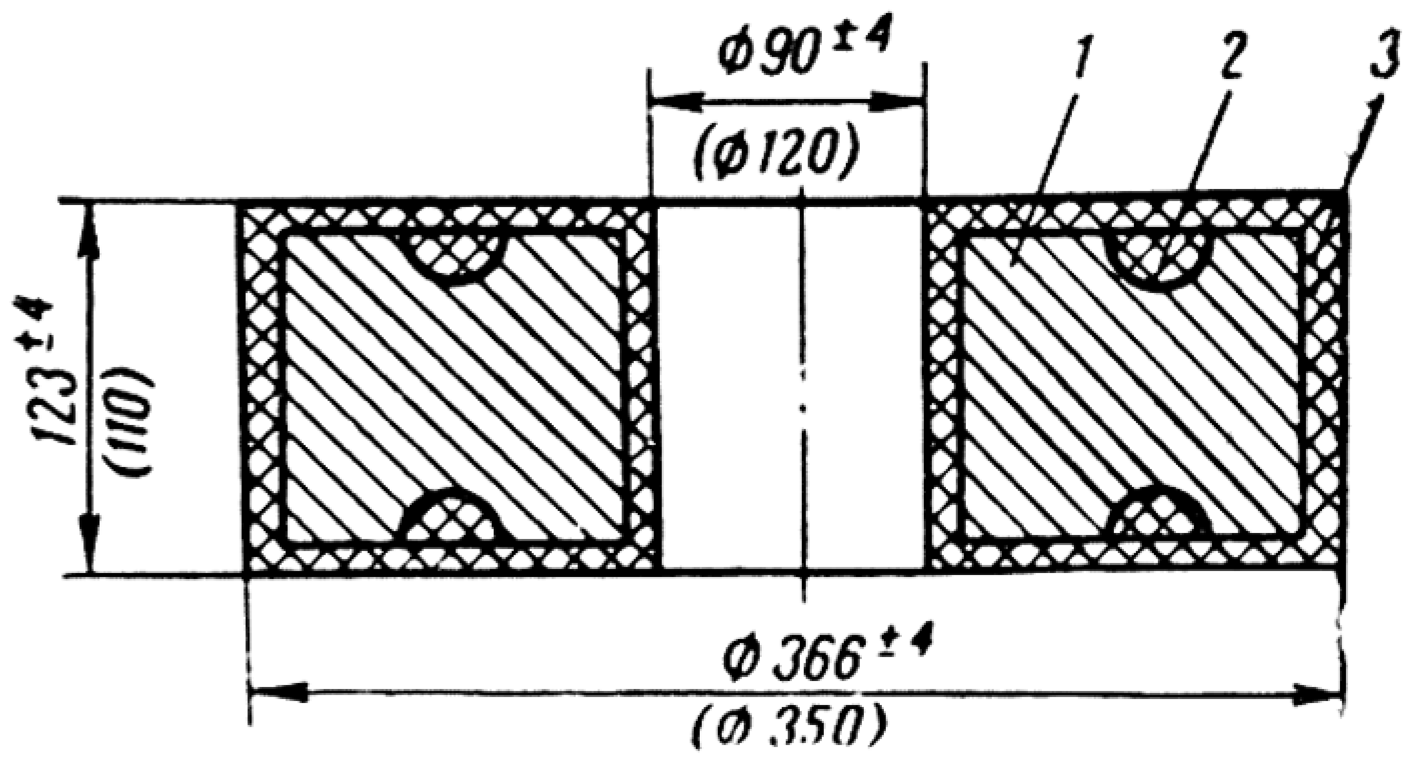


Fig. 140. Forging drawing of a gear blank: 1) contour of gear after machining; 2) forging allowance; 3) contour of gear blank forging

On the completion of the above-mentioned calculations, the contour of the forging is drawn in thick lines around the contour of the finished work; the forging dimensions and tolerances are then written on the drawing, taking additional allowances into account (see Fig. 140).

Example 2. It is required to make a forging drawing of the shaft shown in Fig. 141. The forging is of Type 2, i. e., it is a stepped forging with a round cross-section.

As in Example 1, a scale drawing of the finished shaft, in thin lines, is made (Fig. 141). Then the machining allowances and the forging tolerances are selected. The data of the tables given in Appendixes 2 and 3 refer to forgings of the shape shown in Fig. 141, where $l>0.3D$, and $h_{1,\ 2,\ 3}$ and $_4=5$ mm (l—being the length of the cylinder, D—the diameter of the cylinder, and h—the height of the shoul-

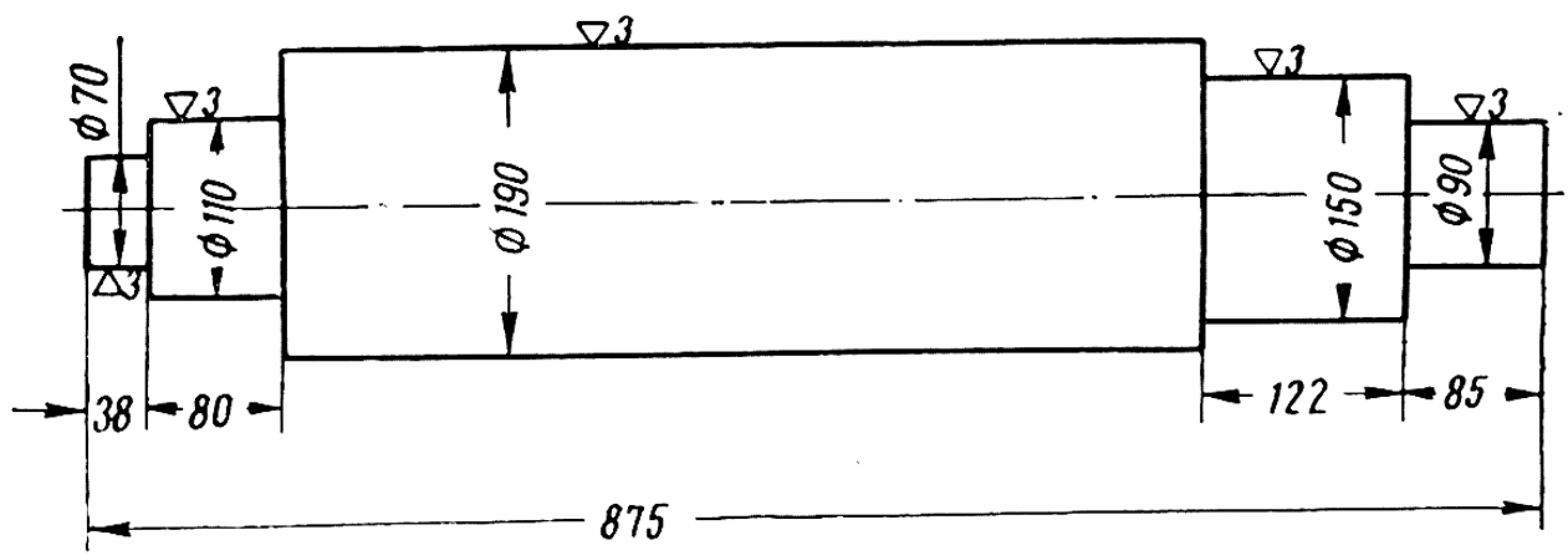


Fig. 141. Designer's drawing of a shaft

der). The basic allowances and tolerances for the dimensions of sections D_0, D_1, D_2, D_3 and D_4 will depend on the dimensions of each of these sections and on the total length of the shaft.

Additional allowances are also specified in addition to the basic allowances for the various sections of a stepped shaft. The magnitude of these additional allowances, S_1, S_2, S_3, and S_4, for the diameter of each step, depending on the difference between the greatest diameter D_0 of the shaft and the diameters D_1, D_2, D_3 and D_4 of each step, can be found in the tables (see Appendix 3). These additional allowances are calculated either for the diameters D_1, D_2, D_3 and D_4, or for the greatest diameter D_0 of the shaft, depending on the ratio of the length of the step in question to the length of the step having the greatest diameter.

$$\frac{l_1 l_2 l_3 l_4}{l_0}.$$

In this case, the length of the shaft, L, is 875 mm; the diameters of each section are: $D_0=190$ mm; $D_1=70$ mm; $D_2=110$ mm; $D_3=150$ mm; $D_4=90$ mm. The lengths of the steps are: $l_1=38$ mm; $l_2=80$ mm; $l_3=122$ mm; $l_4=85$ mm; and the length of step $l_0=550$ mm. From the tables in Appendix 3, the basic allowances and tolerances for the diameters of each step are selected, as follows:

For diameter $D_0=190$ mm, the basic allowance a_0 will be 15^{+4}_{-3} mm;
For diameter $D_1=70$ mm, the basic allowance a_1 will be 10^{+2}_{-3} mm;
For diameter $D_2=110$ mm, the basic allowance a_2 will be 12^{+3}_{-4} mm;
For diameter $D_3=150$ mm, the basic allowance a_3 will be 13 ± 4 mm;
For diameter $D_4=90$ mm, the basic allowance a_4 will be 12^{+3}_{-4} mm.

Then the additional allowances are determined and specified for the corresponding sections (steps) of the shaft according to the tables of Appendix 3. This done, the total allowance for each section of the shaft is calculated:

For diameter D_1 an additional allowance $S_1=6$ mm is specified since the ratio $\frac{l_1}{l_0}=\frac{70}{150}=0.12$ is less than the ratio 2.6 given in the table for a section of diameter $D_1=70$ mm;
For diameter D_2 an additional allowance $S_2=4$ mm is specified;
For diameter D_3 an additional allowance $S_3=3$ mm;
For diameter D_4 an additional allowance $S_4=6$ mm.

No additional allowance is specified for diameter D_0 of a section of the given dimensions. Thus the full allowance and tolerances for the diameters of each section of the shaft will be:

For diameter $D_0=190$ mm, full allowance $a_0=15^{+4}_{-3}$ mm;
For diameter $D_1=70$ mm, full allowance $(a_1+S_1)=10+6=$
$=16^{+2}_{-3}$ mm;
For diameter $D_2=110$ mm, full allowance $(a_2+S_2)=12+4=$
$=16^{+3}_{-4}$ mm;
For diameter $D_3=150$ mm, full allowance $(a_3+S_3)=13+3=$
$=16\pm4$ mm;
For diameter $D_4=90$ mm, full allowance $(a_4+S_4)=12+6=$
$=18^{+3}_{-4}$ mm;

When specifying additional allowances, the tolerance $\left(\frac{\Delta}{2}\right)$ is not increased and is selected to correspond to the tolerance for the basic allowance. Consequently, the forging diameters of the shaft, and its tolerances, will be as follows:

$$D_0'=190+15^{+4}_{-3}=205^{+4}_{-3}\text{ mm};\quad D_1'=70+16^{+2}_{-3}=86^{+2}_{-3}\text{ mm};$$
$$D_2'=110+16^{+3}_{-4}=126^{+3}_{-4}\text{ mm};\quad D_3'=150+16\pm4=166\pm4\text{ mm};$$
$$D_4'=90+18^{+3}_{-4}=108^{+3}_{-4}\text{ mm}.$$

The allowances and tolerances for sections l_1, l_2, l_3 and l_4 will be calculated from the initial basis, and will be equal to those for the dimensions of the largest section D_0 and the total length L of the shaft. In this case, for a shaft of diameter $D_0=190$ mm and $L=875$ mm, the allowance (b) and tolerance ($\pm\frac{\Delta}{2}$) for the length of

the shaft and the length of its various sections (see Appendix 2) will be: $b=45\pm15$ mm, or, per side: $\frac{b}{2}=22.5\pm7.5$ mm.

A sketch of the shaft, specifying the allowances, is given in Fig. 142.

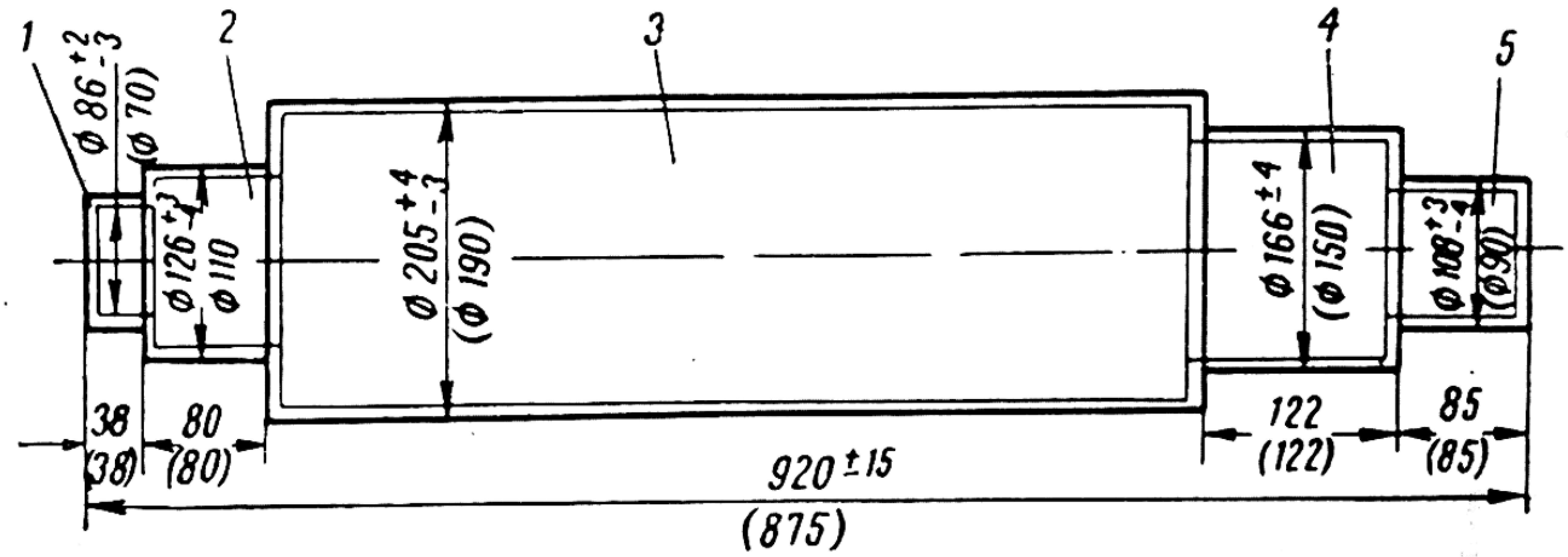


Fig. 142. Forging drawing of shaft, shown in Fig. 141

After determining the allowances, the possibility of forging the sections of the shaft is checked against the tables of Appendix 5; the selected allowances and additional allowances are also verified.

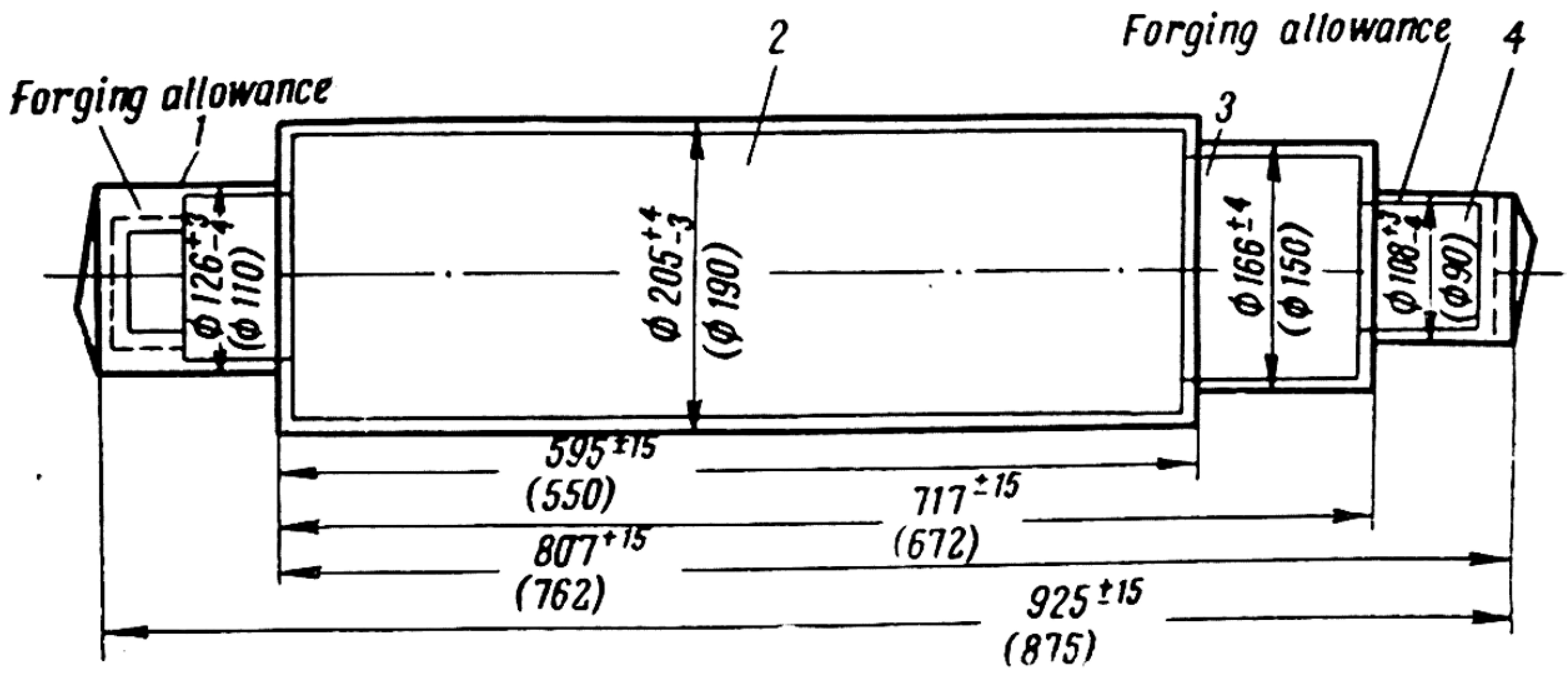


Fig. 143. Drawing of forging (forging drawing)

According to the tables of Appendix 5 (a), the length l of the forged tail section, adjacent to the section having a diameter $D_2'=126$ mm, must be longer than the maximum length of 45 mm (see Fig. 142). Actually, however, the length l_1 of this section is 38 mm, i. e., less than the maximum. Therefore, this section is not forged separately, but is given an allowance making its diameter the same as its adjacent section, $D_2=126$ mm (see Fig. 143). Intermediate section *2* is forged to the same diameter as section *1*. The sum of the length of

sections *1* and *2* ($l_1'+l_2'=118$ mm), is greater than the maximum, permissible when the diameter D_0' of the adjacent section is 205 mm. From these considerations, this section must be forged without any additional allowance for length (see Appendix 5, *b*).

Intermediate section *4* is forged. Its length $l_3'=122$ mm is greater than the maximum (60 mm) when the diameter D_0' of the adjacent section *3* is 205 mm. The length l_4 of second tail section *5*, is 85 mm, which is greater than the maximum length (55 mm) for an adjacent section with a diameter $D_3'=166$ mm. But, according to the tables of Appendix 5 (*b*), the length of this section is less than the maximum (90 mm) and will therefore have to be forged with an additional allowance to a length equal to the maximum length, i.e., to a length of 90 mm.

After checking the possibility of forging each section, the final outline and dimensions of the forging are determined, it is drawn in thick lines and the forging dimensions are written in. This done, the drawing of the forging is considered as being complete. Fig. 143 shows the drawing of the forging with final dimensions and additional allowances.

ENGINEERING SPECIFICATIONS FOR FORGINGS AND THE SELECTION OF STOCK FOR FORGING

Every forging made in a forge shop must meet definite requirements, or *engineering specifications*, as they are called. As a rule, these specifications are indicated in the *technological (process) charts*; if, as an exception to this rule, a forging is to be made without a process chart, the necessary specifications are given in the forging drawing.

The engineering specifications must indicate: 1) the grade and chemical composition of the steel from which the forging is to be made; 2) the forging method and conditions (when forging responsible parts); 3) the necessary mechanical tests and the number of test specimens, their dimensions, and the places where they are to be taken from; 4) the specifications of the mechanical tests; 5) the conditions to be satisfied with regard to surface finish of a forging, specifying the maximum depth of surface defects (cracks, blebs, hair-seams, laps, etc.); 6) the requirements for marking the forging.

On the basis of the forging drawing it is always possible to calculate the weight of the metal required for the production of the forging. The weight of metal required for making a given forging from an ingot will be:

$$W_{ing}=W_{forg}+W_{h.disc}+W_{b.disc}+W_{sc}+W_{crop}\ \text{kg},$$

where W_{in} is the weight of the initial material, in kilograms;
W_{forg} — the weight of the forging;
$W_{h.disc}$ — the weight of the ingot head discard;
$W_{b.disc}$ — the weight of the ingot bottom discard;
W_{sc} — weight of loss due to scale;
and W_{crop} — weight of loss due to croppings.

The weight of metal required for making a forging from rolled stock will be:

$$W_{ing}=W_{forg}+W_{crop}+W_{sc} \text{ kg.}$$

Where W_{in} is the weight of the initial material, in kilograms;
W_{forg} — the weight of the forging;
W_{crop} — the weight of the croppings and the sludge;
W_{sc} — the weight of loss due to scale.

Calculating the Volume and Weight of a Forging (W_{forg}). The volume and the weight of a forging are calculated from the forging drawing. The volume of the metal in small and medium-size hammer forgings is usually calculated in cubic centimetres, and the volume of heavy press forgings in cubic decimetres. The weights are correspondingly calculated in grams and kilograms.

The *weight of a forging* is equal to the product obtained when its volume is multiplied by the specific gravity of the metal from which it is made. To calculate the volume of forgings made up of irregular sections, or having complicated configurations, they are divided into separate sections of definite simple geometric patterns, such as: cylinders, spheres, cones, etc.

When calculating the volume and weight of heavy forgings and especially of stepped shafts, it is absolutely necessary to take into calculation the amount of metal required for ensuring the transition from one diameter to another. Fig. 144 gives a *nomogram for calculating the weight of metal* required for the transition from one diameter to another in cylindrical sections. The weight of metal so calculated is added to the weight of the forging.

This nomogram is employed in the following way:

1) First, half the sum of the adjacent diameters, $\frac{D+d}{2}$ mm is calculated and the resulting value marked off on the right-hand scale;

2) Then half the difference of the same adjacent diameters $\frac{D-d}{2}$ mm is calculated, and the resulting value marked off on the left-hand scale;

3) The points so marked off on the right-hand and the left-hand scale are joined by a straight line, which will intersect the middle scale at a point G; this point G will indicate the weight of metal in kilograms required for the transition of the forging from diameter D to a lesser diameter d.

Let us suppose that the weight of metal required for the transition of one section of a forging to another, smaller section, has to be calculated when the diameter of the first section, $D=1{,}000$ mm, and the diameter d, of the adjacent section, is 500 mm.

Half the sum of the diameters will be:

$$\frac{1{,}000+500}{2}=\frac{1{,}500}{2}=750\ \text{mm};$$

and half the difference of the diameters,

$$\frac{1{,}000-500}{2}=\frac{500}{2}=250\ \text{mm}.$$

750 is marked off on the $\frac{D+d}{2}$ scale, and 250 on the $\frac{D-d}{2}$ scale; and the points so marked are joined by a straight line which intersects the middle scale at a point corresponding to 100. Consequently, the weight of the metal required for the transition of section $D=1{,}000$ to section $d=500$, will be 100 kg.

Example 1. Calculate the weight of a forging for the gear blank shown in Fig. 140 (stock—grade Ct. 3 steel).

The volume of the forging will be:

$$V_{forg}=\left(\frac{\pi D^2}{4}-\frac{\pi d^2}{4}\right)H\ \text{cm}^3,$$

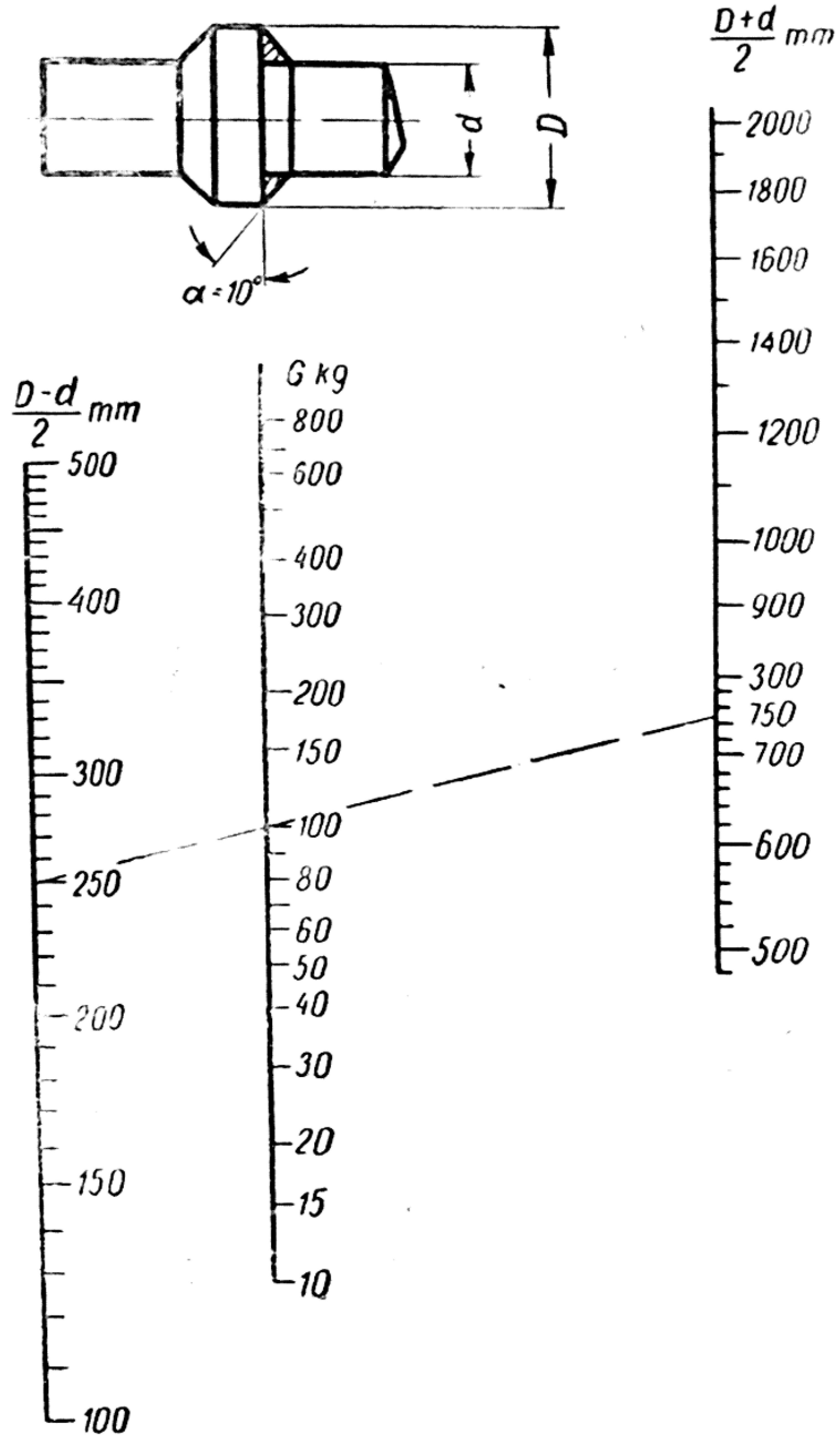


Fig. 144. Nomogram for determining the weight of metal for transition from one section to another of smaller diameter

where D—outside diameter of forging $=36.6$ cm;
H—height of forging (gear blank) $=12.3$ cm;
d—diameter of hole in gear blank $=10.0$ cm.

Substituting figures for the symbols, the volume of the forging, V_{forg} will be:

$$V_{forg}=\left(\frac{3.14\times 36.6^2}{4}-\frac{3.14\times 10^2}{4}\right)12.3=11{,}968.0 \text{ cm}^3.$$

The weight of the forging will be:

$$W_{forg}=V_{forg}\times g \text{ kg},$$

where g—the specific gravity of the metal (steel)$=7.85$ g/cm³.
By substitution,

$$W_{forg}=\frac{11{,}968.0\times 7.85}{1{,}000}=93.9\approx 94 \text{ kg}.$$

Example 2: Calculate the weight of the shaft forging shown in Fig. 143 (material—grade Cт. 3 steel).

The entire forging has to be divided into four sections:

1) A cylinder of length $l_1=11.8$ cm, diameter $D_1=12.6$ cm;
2) A cylinder of length $l_2=59.5$ cm, diameter $D_2=20.5$ cm;
3) A cylinder of length $l_3=12.2$ cm, diameter $D_3=16.6$ cm;
4) A cylinder of length $l_4=9.0$ cm, diameter $D_4=10.8$ cm.

The volume of the forging V_{forg} will be equal to the sum of the volumes of its four component sections.

$$V_{forg}=V_1+V_2+V_3+V_4 \text{ cm}^3.$$

The volume of the first section will be:

$$V_1=\left(\frac{\pi D_1^2}{4}l_1\right)=\frac{3.14\times 12.6^2}{4}\times 11.8=1{,}471.5 \text{ cm}^3.$$

The volume of the second section will be:

$$V_2=\frac{\pi D_2^2}{4}l_2=\frac{3.14\times 20.5^2}{4}\times 59.5=19{,}641 \text{ cm}^3.$$

The volume of the third section will be:

$$V_3=\frac{\pi D_3^2}{4}l_3=\frac{3.14\times 16.6^2}{4}\times 12.2=2{,}640 \text{ cm}^3.$$

The volume of the fourth section will be:

$$V_4=\frac{\pi D_4^2}{4}l_4=\frac{3.14\times 10.8^2}{4}\times 9=824.5 \text{ cm}^3.$$

The volume of the entire forging will be:

$$V_{forg}=1{,}471.5+19{,}641+2{,}640+824.5=24{,}577 \text{ cm}^3.$$

The weight of the forging will be:

$$W_{forg}=V_{forg}\times g=\frac{24,577\times 7.85}{1,000}=193 \text{ kg}.$$

In this case, the volume of metal required for the transition from one diameter to another is neglected, as the difference in the diameters is insignificant and the volume of metal required for the transitions is also negligible.

Determining the Loss of Metal During Hammer Forging. In hammer forging, the following losses of metal are met with: ingot head and bottom discard, when forging from an ingot; loss due to scale during heating and forging; slug (when making hollow forgings), croppings and remainder.

Metal losses due to ingot top and bottom discard are unavoidable when forging from the ingot. The weight of the head discard, $W_{h.disc}$ is usually taken as from 14 to 25 per cent of the weight of the ingot, when making forgings from structural carbon steels, and up to 35 per cent of the weight of the ingot when making forgings from alloy steels.

The weight of the ingot bottom discard $W_{b.disc}$ for ingots of structural carbon steel is taken as being from 5 to 7 per cent, and for ingots of alloy steel—from 7 to 10 per cent of the weight of the entire ingot. It should always be borne in mind that the loss of metal is least when making hollow forgings, and greatest when making solid forgings.

Loss of metal due to scale is also unavoidable in forging practice. For calculating the weight of the stock, loss due to scale is usually taken as being from 2 to 3 per cent of the weight of the stock or ingot for full heating, and as 1.5 to 2 per cent for each extra heat. When heating in blacksmith's hearths, where the fuel comes in direct contact with the steel, the loss due to scale reaches 4 to 5 per cent of the weight of the stock per full heat.

The loss due to scale when heating alloy steels is considered as being less than that when heating carbon structural steels.

Slug is the loss of metal entailed when punching holes in forgings. The volume and weight of slug losses are determined by calculation. Generally, the height of the slug is taken as being one-third of the full height of the forging H in which the hole is punched $\left(\frac{H}{3}\right)$.

After calculating the weight of metal required for making a given forging, the corresponding ingot or rolled stock must be selected. Ingots are always cast to definite weights, and it often happens that an ingot of the required weight is not readily available. In this case an ingot must be selected with a weight approximating as nearly as possible to that required, but which must always be more, and never less, than the calculated weight.

The difference between the weight of the available ingot and the weight of the calculated ingot comprises the waste as remainder. When making forgings from rolled sections, remainders occur as shear waste when the bar stock cannot be cut up in an exact number of lengths for forging. This waste can be utilised for making other forgings.

Croppings are unavoidable losses entailed in any technological process of forging. As a rule, they are formed at the ends of the forging and their dimensions and weight depend on the shape and cross-sectional area of the stock.

The *volume of the croppings* can be calculated from the following formulas.

For press forgings:
for cylindrical sections of diameter D

$$V_{crop}=0.21D^3,$$

for rectangular sections of width B and height H:

$$V_{crop}=0.28B^2H.$$

For hammer forgings:
for cylindrical sections of diameter, d

$$V_{crop}=0.23d^3,$$

for rectangular sections of width W and height H:

$$V_{crop}=0.3B^2H.$$

Cropping losses can also be calculated as a percentage of the weight of the forging, as indicated in Table 6.

Table 6

Table of Losses of Metal Due to Croppings

Type of forging	Loss, in per cent
Forgings of simple shape (shafts, discs)	5-10
Stepped and flanged shafts	10-20
Connecting rods (various shapes)	15-20
Levers	14-25
Small crankshafts with flanges	25-30
Locomotive connecting rods	20-30

Selecting the Initial Stock. After calculating the initial weight of metal (W_{in}) required for making any given forging, the problems of the profile and dimensions of the ingot or rolled stock must be decided.

If the forging is to be made from rolled stock, the profile and dimensions of the rolled stock must meet the following requirements:

1. If the forging is to be made by drawing (without upsetting), the dimensions of the cross-section of the rolled stock must ensure a minimum reduction factor of 1.3-1.5 for blooms, and of 1.1-1.3 for ordinary rolled stock.

2. If the forging is to be upset, the maximum ratio between the length of the stock and its diameter (and, for square stock—the length of the side of the square) must not exceed 2-2.5. If the length of the piece of stock is more than 2.5 times its diameter, or its thickness, it is quite possible that the work will buckle during upsetting.

When the forging is to be made from an ingot, the first question to be decided is the number of forgings which are to be produced from one ingot. This will depend on the weight and designation of the forging. If the forging is intended for an important part of a machine, it will, as a rule, be made from a separate ingot, taking into consideration the fact that, the lighter the ingot, the better the quality of the metal will be. For less important parts, and if the proper equipment is available, it is necessary to select ingots of sufficient weight to make several forgings; in this case metal is saved and the time for producing the forgings reduced. Moreover, when making forgings from ingots by drawing, an ingot must be selected the cross-section of which will ensure a reduction factor of 3; otherwise the forging will entail end-upsetting.

The *weight of an ingot* for making a given forging is calculated as follows:

1) The weight of the stock is calculated;

2) The weight of each of the following elements are calculated: loss of metal due to scale, croppings, slug, ingot head and bottom discard, etc;

3) From the total weight of the ingot, which is taken as 100 per cent, are then subtracted, in percentages, the total weight of loss and waste metal: loss due to scale, ingot head and bottom discard. The resulting percentage expresses the weight of metal required for making the forging, including the croppings.

The theoretical weight of an ingot can be calculated from the following formula:

$$W_{ing} = \frac{(W_{forg} + W_{waste}) \times 100}{\eta} \text{ kg},$$

where: W_{ing} —theoretical weight of ingot, in kilograms,
W_{forg} —weight of forging, in kilograms,
W_{waste} —weight of losses (scale losses+head discard+bottom discard)

$$W_{waste} = W_{sc} + W_{h.\ disc} + W_{b.\ disc};$$

η — permissible percentage of ingot metal which can be utilised:

$$\eta = 100-(W_{sc}+W_{h.\ disc}+W_{b.\ disc})\ \%.$$

Example. Required to make a smooth shaft of the following forging dimensions: diameter $D=800$ mm; length $l=5$ m. The forging will require two heatings. Select an ingot for the above forging.

Solution. Volume of forging, in cubic decimetres:

$$V_{forg}=\frac{\pi D^2}{4}l=\frac{3.14\times 8.0^2}{4}\times 50.0=2,612\ \text{dm}^3.$$

Weight of forging, W_{forg} will be:

$$V_{forg}\times g=2,612\times 7.85=20,500\ \text{kg},$$

where g — specific gravity of the metal$=7.85$ kg per cubic decimetre.

The loss of metal due to scale, W_{sc}, incurred in two heatings will be:

$$2+1.75=3.75\ \text{per cent}.$$

The weight of the ingot head and bottom discards are presumed to be $W_{h.disc}=20$ per cent and $W_{b.disc}=5$ per cent.

According to Table 6, the loss of metal as croppings, W_{crop} is 5 per cent of the total weight of the forging or:

$$W_{crop}=20,500\times 0.05\approx 1,025\ \text{kg}.$$

Thus, the total weight of the waste: ingot head discard+ingot bottom discard+loss due to scale, will be:

$$20+5+3.75=28.75\%.$$

The weight of metal, in per cents, for the forging plus croppings will be:

$$\eta=100-28.75=71.25\ \text{per cent}.$$

The theoretical weight of the ingot will be:

$$W_{ing}=\frac{(W_{forg}+W_{crop})}{\eta}\times 100=\frac{(20,500+1,025)}{71.25}\times 100\approx 30,310\ \text{kg}.$$

The ingot is selected from the table in Appendix 1. As this table does not specify an ingot of the required weight, one approximating to it is selected; the weight of this ingot will be 32,368 kg.

Below are given several examples of selecting ingots.

Example 1. Select an ingot for making the forging of the gear blank shown in Fig. 140.

Solution. The weight of the initial stock for making the forging of the gear blank will be:

$$W_{in}=W_{forg}+W_{sc}+W_{waste}\ \text{kg}.$$

It was previously calculated that the weight of the gear blank forging, W_{forg}, was 94 kg, and that its volume, V_{forg}, was 11,968.0 cm³. This is considered a light forging and will therefore be upset from a rolled steel bar. The only loss of metal incurred will be the slug when punching the hole for the shaft in the gear blank. The diameter of the slug is presumed to be the same as that of the hole; its height will be one-third of the height of the forging.

The diameter of the slug, d_{sl} is 100 mm.

The height of the slug, $h_{sl}=1/3\ H=\frac{123}{3}=41$ mm.

The volume of the slug will therefore be:

$$V_{sl}=V_{waste}=\frac{\pi d^2}{4}\times h=\frac{3.14\times 10^2}{4}\times 4.1=322\ \text{cm}^3.$$

The forging is to be made in one heat, and therefore the losses due to scale V_{sc} will be about 2 per cent of the volume of the stock. The weight of the initial stock is taken as 100 per cent. The volume of metal lost as scale will be:

$$V_{sc}=\frac{(V_{forg}+V_{sl})\,V_{sc}}{100-V_{sc}}=\frac{(11{,}968+322)\,2}{100-2}=251\ \text{cm}^3.$$

The volume of the initial stock will be:

$$V_{in}=V_{forg}+V_{sc}+V_{sl}=11{,}968+251+322=12{,}541\ \text{cm}^3.$$

The *dimensions of the stock* for making the forging of the gear blank are calculated on the basis of the following considerations (the forging will be upset):

1. *Convenience of upsetting.* The shorter the stock, the more convenient will it be to upset it. The stroke of the ram and the capacity of the hammer on which the forging is to be made must be taken into consideration. The shorter the piece of stock, the longer will be the stroke of the ram, and the easier the upsetting operation.

2. The *possibility* of cutting or shearing the stock from the bar *approximating as nearly as possible* in volume or weight to that necessary for making the part in question. In this case, the opposite holds good: the longer the piece of stock, i. e., the greater the ratio of its length to its diameter or side of square, the closer will be the volume of the piece of stock which can be cut off or sheared to that required for making the given part.

3. The availability of the selected size of material.

4. The length of the stock must not exceed 2 to 2.5 diameters or sides of its square, inasmuch as the forging is to be upset.

Taking all the above-mentioned considerations into account, in this case a square bar 200×200 mm or a 200 mm diameter round bar is selected. The required length of the stock will be:

$$L=\frac{V_{in}}{A_{stock}},$$

where L—length of stock,

V_{in}—volume of initial material, and

A_{stock}—cross-sectional area of stock.

By substitution we obtain:

$$L=\frac{12,541}{20\times 20}=\frac{12,541}{400}=31.0\ \text{cm}=310\ \text{mm}.$$

It is necessary to see whether the selected length of the stock meets the requirements of the fourth condition:

$$\frac{L}{d}=1.5\ \text{to}\ 2.0=\frac{310}{200}\approx 1.55.$$

Thus, a piece of stock 200 mm in diameter or 200×200 mm in cross-section and 310 mm long will be quite suitable for the forging.

Example 2. It is reguired to select a piece of stock for making a forging of the stepped shaft shown in Fig. 143.

Solution. The volume of the initial stock V_{in} will be:

$$V_{forg}+V_{sc}+V_{waste}\ \text{cm}^3.$$

The volume and weight of this forging have already been calculated above, and will be 24,577 cm³ and 193 kg respectively.

During the forging of the shaft, waste metal will be incurred when cropping the ends of the forging. Therefore, before calculating the weight of the waste metal, it must be decided which process to employ for forging the shaft. If it is forged from stock long enough to make only one shaft cut from a bar, the waste will be cropped off from both ends of the stock. On the other hand, if the shaft is forged from a long bar and then cut off, the waste will be cropped from only one end of the bar. In this case it is taken that the shaft will be forged from a piece of stock long enough for one shaft only.

The volume of metal lost as croppings from both ends of the shaft can be calculated from the formula (for hammer forging):

$$V_{crop}=0.23d^3\text{cm}^3,$$

where d is the diameter of the cropping.

For this forging, the volume of metal lost as croppings from each end of the shaft will be:

from the left-hand end

$$V'_{crop}=0.23d_1^3=0.23\times 12.6^3=460\ \text{cm}^3;$$

from the right-hand end

$$V''_{crop}=0.23d_2^3=0.23\times 10.8^3=290\ \text{cm}^3.$$

Total loss of metal as croppings will therefore equal:

$$V_{crop}=V'_{crop}+V''_{crop}=460+290=750\ \text{cm}^3.$$

According to practical data, the shaft will be forged in one heat. The loss of metal due to scale is calculated as 2 per cent of the volume or weight of the stock itself. The volume of the metal of the stock is taken as 100 per cent.

The volume of metal lost as scale will therefore be:

$$V_{sc}=\frac{(V_{forg}+V_{crop})\,V_{sc}}{100-V_{sc}}=\frac{(24,577+750)\,2}{100-2}=517\ \text{cm}^3.$$

The volume of the initial stock will therefore be:

$$V_{in}=V_{forg}+V_{sc}+V_{crop}=24,577+517+750=25,844\ \text{cm}^3.$$

The weight of the stock will, correspondingly, equal:

$$W_{in}=\frac{25,844\times 7.85}{1,000}=203\ \text{kg}.$$

When calculating the dimensions of the stock for making the above-mentioned forging, the material from which the forging will be made (ingot or rolled stock), must be taken into account, as well as the method of forging the shaft. The forging is comparatively light and therefore it will be more economical to make it from rolled stock. If the stock is to be drawn out (reduced), the reduction factor must be from 1.3 to 1.5 to ensure a high-quality forging.

In this case, the reduction factor is taken as 1.4. The greatest diameter of the shaft, D, is 205 mm (see Fig. 143). Correspondingly, the greatest cross-sectional area of the shaft will be:

$$A_{shaft}=\frac{\pi D^2}{4}=\frac{3.14\times 20.5^2}{4}=330\ \text{cm}^2.$$

For a reduction factor of 1.4, the cross-sectional area of the stock must be:

$$A_{stock}=A_{shaft}\times 1.4=330\times 1.4=462\ \text{cm}^2.$$

This cross-sectional area corresponds to that of a square bar 215×215 mm. GOST 4692 does not specify blooms of this size, so a bloom of the nearest cross-section 220×220 mm must be selected. The length of the stock required will be:

$$L_{stock}=\frac{V_{in}}{A_{stock}}=\frac{25,844}{484}=53.6\ \text{cm}=535\ \text{mm}.$$

Thus, for the shaft forging a bloom of $L=535$ mm, and cross-section 220×220 mm is required.

Example 3. Required to make a forging drawing of the stepped shaft shown in Fig. 145.

Solution. First of all a scale drawing of the external contour of the shaft (in thin lines) is made and the basic dimensions are written in.

This is a Type 2 forging (see Fig. 138), i. e., it is of round section, stepped, and of large dimensions; it will have to be made in a forging

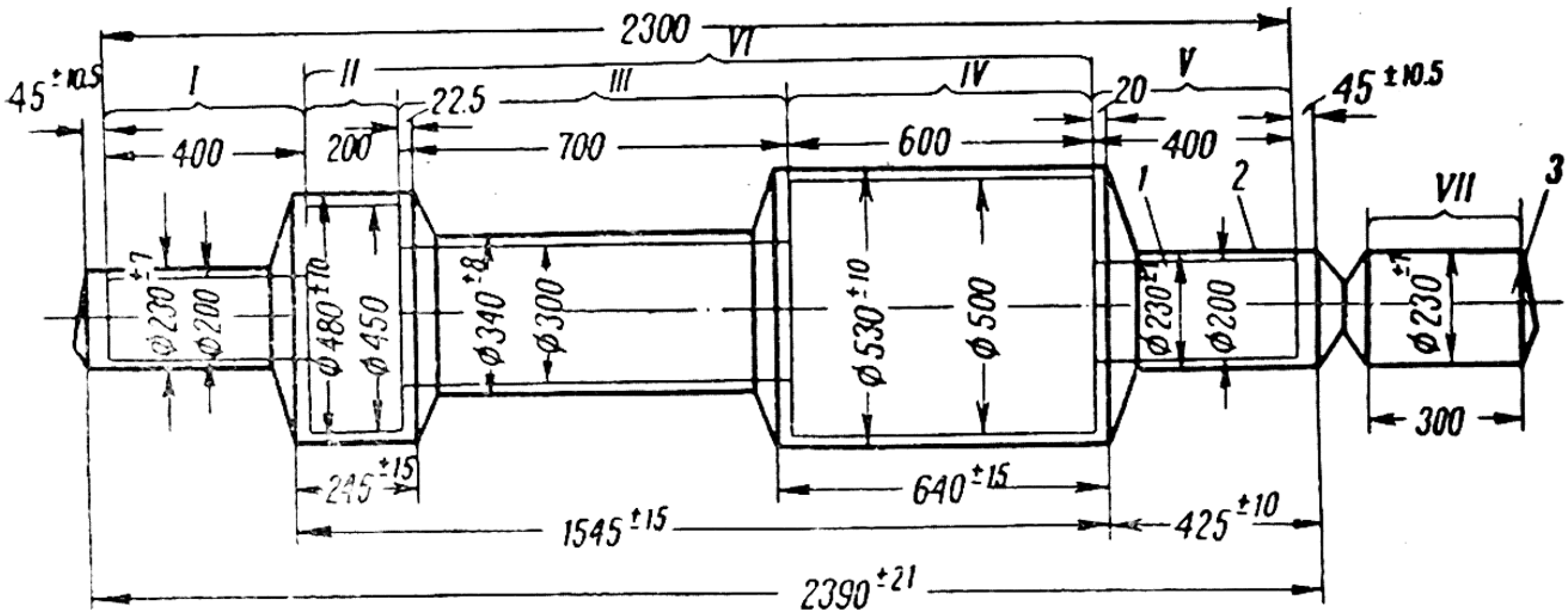


Fig. 145. Forging drawing of a stepped shaft:
1) contour of shaft after machining; 2) shaft forging; 3) test specimen

press. The machining allowances and forging tolerances will be selected from the tables of Appendix 3 for the dimensions of each section of the shaft, depending on its dimension and on the total length of the shaft. Moreover, it must be borne in mind that, for necked shafts, the allowances for the diameters of the necks and steps D_1, D_2 and D_3 must be increased, as compared with the allowances for forgings of smooth round cross-section, by an amount x equal to 0.07 of the step h_1, h_2, and h_3, i. e., by 0.07 h_1 for diameter D_1, by 0.07 h_2 for diameter D_2, and by 0.07 h_3 for diameter D_3.

When increasing the allowance by x, the tolerances $(\pm\frac{\Delta}{2})$ given in the tables are not altered.

The allowance per side for the length of the forging is equal to 0.75 a, for the length of each shoulder, and 1.5a—for the length of each end of the forging, where a is the allowance for each corresponding diameter.

No allowances or tolerances will be specified for the necks. The allowance for the diameter of each section of the forging is now calculated.

For a shaft with a length $L=2{,}300$ mm and diameter of section I $D_1=200$ mm, the allowance a for the diameter will be 20 mm (see Appendix 3). As is already known, the allowance for diameter I will be increased by

$$x_I=0.07h_1=0.07\,\frac{D_2-D_1}{2}=0.07\,\frac{450-200}{2}=8.75\ \text{mm}.$$

The full allowance for the diameter of the first section will be $(20+8.75)=28.75$ mm, and the final diameter D, after rounding off to the nearest 0, will be:

$$D_1=200+28.75=228.75\approx 230\ \text{mm}.$$

The allowance for the diameter of the collar (section II) for a length of 2,300 mm and diameter $D_2=450$ mm will be 28 mm (see Appendix 2). The allowance is to be increased by:

$$x_{II}=0.07h_2=0.07\,\frac{D_4-D_2}{2}=0.07\,\frac{500-450}{2}=1.75\ \text{mm}.$$

The full allowance on the diameter of section II will be $28+1.75$ mm. Thus, the final diameter will be:

$$D_2=450+29.75=479.75\approx 480\ \text{mm}.$$

The allowance for the diameter of the necked section (section III) for the length $L=2{,}300$ mm and having diameter $D_3=300$ mm will be 24 mm. The increased allowance x_{III} will be:

$$0.07h_3=0.07\,\frac{D_4-D_3}{2}=0.07\,\frac{500-300}{2}=7\ \text{mm}.$$

The full allowance for the diameter of necked section III, will be $24+7=31$ mm, and the final diameter of this necked section will be:

$$D_3=300+31=331\approx 330\ \text{mm}.$$

The allowance on the diameter of the collar (section IV) over a length $L=2{,}300$ mm and diameter $D_4=500$ mm will be 28 mm. The diameter of section IV will be:

$$D_4=500+28=528\approx 530\ \text{mm}.$$

The allowance for the end stepped section (section V) will be taken as 20 mm. The increased allowance x_V will be:

$$0.07h_5=0.07\,\frac{D_4-D_5}{2}=0.07\,\frac{500-200}{2}=10.5\ \text{mm}.$$

The full allowance, a, for the diameter of stepped section V will be:

$$20+10.5=30.5\ \text{mm}.$$

The diameter of section V will therefore be:

$$D_5=200+30.5 \approx 230 \text{ mm}.$$

The allowances and lengths of each section and the total length of the forging are now calculated. The length of section I is included in the total length of the forging. The allowance per side for the length l_2 of section II=200 mm will be 0.75 of allowance a on the diameter D_2=450 mm as follows:

$$2(0.75a)=2(0.75\times 29.75)=4.62 \approx 45 \text{ mm}.$$

The full length l_2 of section II will thus be 200+45=245 mm.

The minimum length of a shoulder of diameter D_4=450 mm and diameter of step D_1=200 mm must be 110 mm (see Appendix 6). According to calculations, however, its length is 245 mm, which is greater than the minimum forging length.

No allowance is specified for the length of section III. The allowance per side for the length of section IV, l_4=600 mm will be 0.75 of the allowance a on diameter D_4=500 mm, as follows:

$$2(0.75a)=2(0.75\times 28)=42 \text{ mm}.$$

The length of section IV will be:

$$l_4=600+42=642 \approx 640 \text{ mm}.$$

The length of section V, including its allowance, will be:

$$l_5=400+(1.5\times 30.5)-(0.75\times 28)=424.75 \approx 425 \text{ mm}.$$

The total length of the forging will thus be:

$$L=(2{,}300+1.5\times 28.75)+(1.5\times 30.5)=2{,}388.8 \approx 2{,}390 \text{ mm}.$$

The length of section VI together with collars and including allowances, will be:

$$l_6=(200+700+600)+(0.75\times 29.75)+(0.75\times 28)= =1{,}544.6\approx 1{,}545 \text{ mm}.$$

The permissible variations (tolerances) for the diameters will depend on the allowances (according to Appendix 3); and the tolerances will not be affected by an increase of the diameters by x. The tolerance on the dimension D_1 will be ± 7 mm, and hence D_1 will be 230 ± 7 mm. In exactly the same way, D_2 will be 480 ± 10, D_3 will be 330 ± 8, D_4 will be 530 ± 10, and D_5 will be 230 ± 7 mm.

The tolerance for the length of the forging and its necks will be as follows.

Variation (tolerance) for the length of section II:

$$(0.75\times 20)\,2=30 \text{ mm},$$

where 20 is the allowance for the diameter of section II, the tolerance for which is ± 15 mm.

Allowance on length of section IV:

$$2\,(0.75\times 20)=30 \text{ mm}.$$

Consequently, the tolerance will be ± 15 mm.

The tolerance for the dimensions of the shoulders along the length of section VI will be

$$(0.75\times 20)+(0.75\times 20)=30 \text{ mm};$$

then the tolerance will be ± 15 mm.

The allowance for the length of section V will be:

$1.5\times 14=21$ mm; the tolerance will be ± 10 mm.

The tolerance for the total length of the forging will be:

$$\pm\frac{\Delta}{2}=\frac{(1.5\times 14+1.5\times 14)}{2}=\frac{42}{2}=\pm 21 \text{ mm}.$$

The nominal length of the forging and its sections, including the tolerances, will be:

$$l_2=245\pm 15 \text{ mm};$$
$$l_4=640\pm 15 \text{ mm};$$
$$l_6=1{,}545\pm 15 \text{ mm};$$
$$l_5=425\pm 10 \text{ mm};$$
$$L_{total}=2{,}390\pm 21 \text{ mm}.$$

After determining the alowances and tolerances the forging drawing is drawn in thick lines around the thin design contour drawing of the shaft, and the forging dimensions and forging allowances are written in, as shown in Fig. 145.

CHAPTER VIII

HAMMERS FOR HAMMER FORGING

GENERAL INFORMATION ON HAMMERS

Heavy machine parts cannot be forged by hand, since the comparatively light blows of a hand or sledge-hammer are unable to produce a great degree of deformation in the metal being forged. Moreover, hand forging is a lengthy process and requires repeated heatings of the metal. For this reason, hammer forging, sometimes also called power or machine forging, is used for the manufacture of heavy forgings. When forging with power hammers, the deformation of the heated metal takes place either under the action of repeated blows, or of gradually applied pressure. Machines which work on forgings by blows are called *hammers*, while those working by pressure are called *presses*.

Forging under hammers or in presses is further divided into *hammer forging*, when the work is forged with the aid of flat dies. and *stamping* or *die forging*, when the forgings are made in stamps. i. e., in blocks containing impressions of the forging to be made.

Hammers are classified as mechanical and air-and-steam hammers. In their turn, the former are further classified into lever-spring hammers, pneumatic and friction hammers. Air-and-steam hammers are sub-classified into single- and double-action hammers. The part of the hammer which serves as a rigid support during forging is called the *anvil block*. The heavy falling part of the hammer is called the *ram*. The lower part of the ram, which comes into direct contact with the forging, is called the *bottom die*. The heavier the falling part of a hammer, and the greater the height and velocity of the fall, the greater will be the force of the blow of the hammer.

The *capacity* or the tonnage of a hammer is determined by the weight of its falling parts. For instance, if the falling parts of a hammer weigh 100 kg, the hammer is rated as a 100 kg hammer; if its falling parts weigh 5,000 kg, the capacity of the hammer is said to be 5 tons. The force of the blow of the hammer is transferred through the forging to the bottom die and then to the anvil block; the greater the capacity of the hammer, the greater will be the force of the blow and, consequently, the greater must be the weight of the anvil block in order to preserve the stability of the hammer.

Each blow of the hammer shakes the anvil block, which transmits

its vibration to the foundation. Of course, the heavier the foundation is, the less susceptible will it be to vibration, but only very large foundations can be completely free from vibration. Moreover, when erecting hammers, it must always be borne in mind that the vibrations to which they are subjected will be transmitted to the adjacent buildings and installations. In order to protect hammers and their mechanisms against vibration, the anvil blocks and frames of powerful hammers are installed on separate foundations, wooden beams being inserted between the base of the anvil block and the foundation itself.

SPRING HAMMERS

The spring hammer shown in Fig. 146 is formed of connecting rod *1* one end of which is connected to sheave *2*, its opposite end being connected to the rear end of spring *3*, which oscillates in bearings *4*

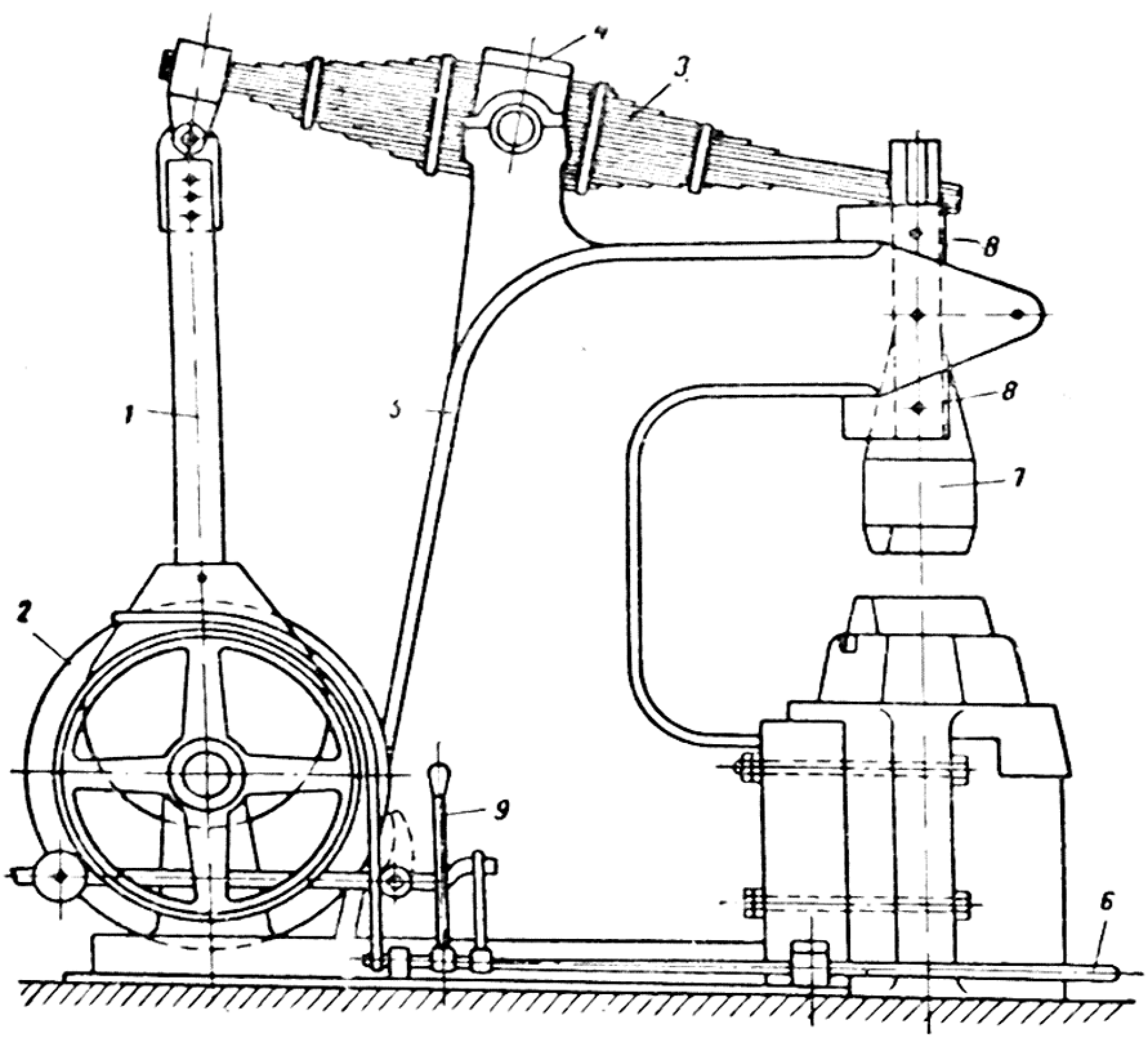


Fig. 146. Spring hammer

secured in frame *5*. When treadle *6* is depressed, the sheave which is connected to the crank gear commences to rotate and the spring to oscillate. Ram *7* of the hammer is connected to the front end of the spring. When the crank gear is depressed, the ram, which travels between guides *8*, will be raised; when the crank gear is raised, the ram will fall and strike the forging on the anvil. The force of the blow, and the height of the ram lift can be regulated by adjusting the stroke of connecting rod *1* through lever *9*.

Spring hammers are built with rams weighing from 30 to 250 kg. Most common are hammers with rams weighing 100 kg with a speed of up to 200 blows per minute, and hammers with rams weighing 50 kg and speeds of up to 300 blows per minute.

The distinguishing feature of spring hammers is the simplicity of their design which permits the regulation of the speed and force of their blows. Their disadvantage is the frequent breaking of springs due to vibrations when in operation.

Spring hammers are generally used for drawing-out (reducing) operations, as well as for drawing in swaging dies.

PNEUMATIC HAMMERS

Pneumatic hammers are mainly employed for hammer forging miscellaneous work and for forging in bolster dies.

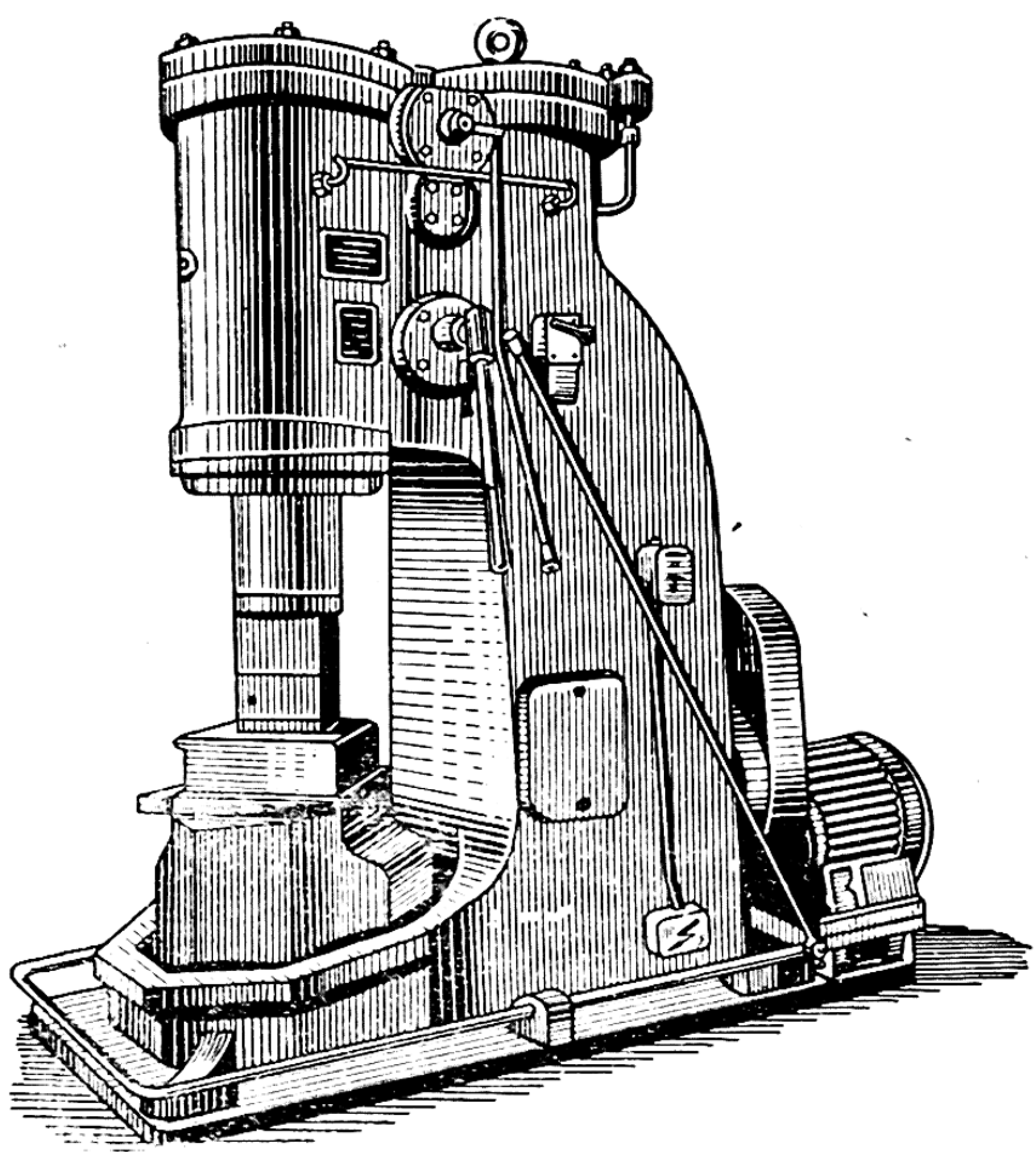


Fig. 147. Pneumatic forging hammer

The most common types of pneumatic hammers are those *driven by an individual electric motor* (Fig. 147). In these hammers the ram can be held suspended in any position, make light or heavy blows as desired, and press the forging to the bottom die of the hammer

if so required. In pneumatic hammers the rams fall not only under their own weight, but are also forced to fall by the action of compressed air above the piston.

Sheave *2* is rotated by electric motor *1* located at the rear of the hammer, through a belt drive (Fig. 148). The sheave is mounted on

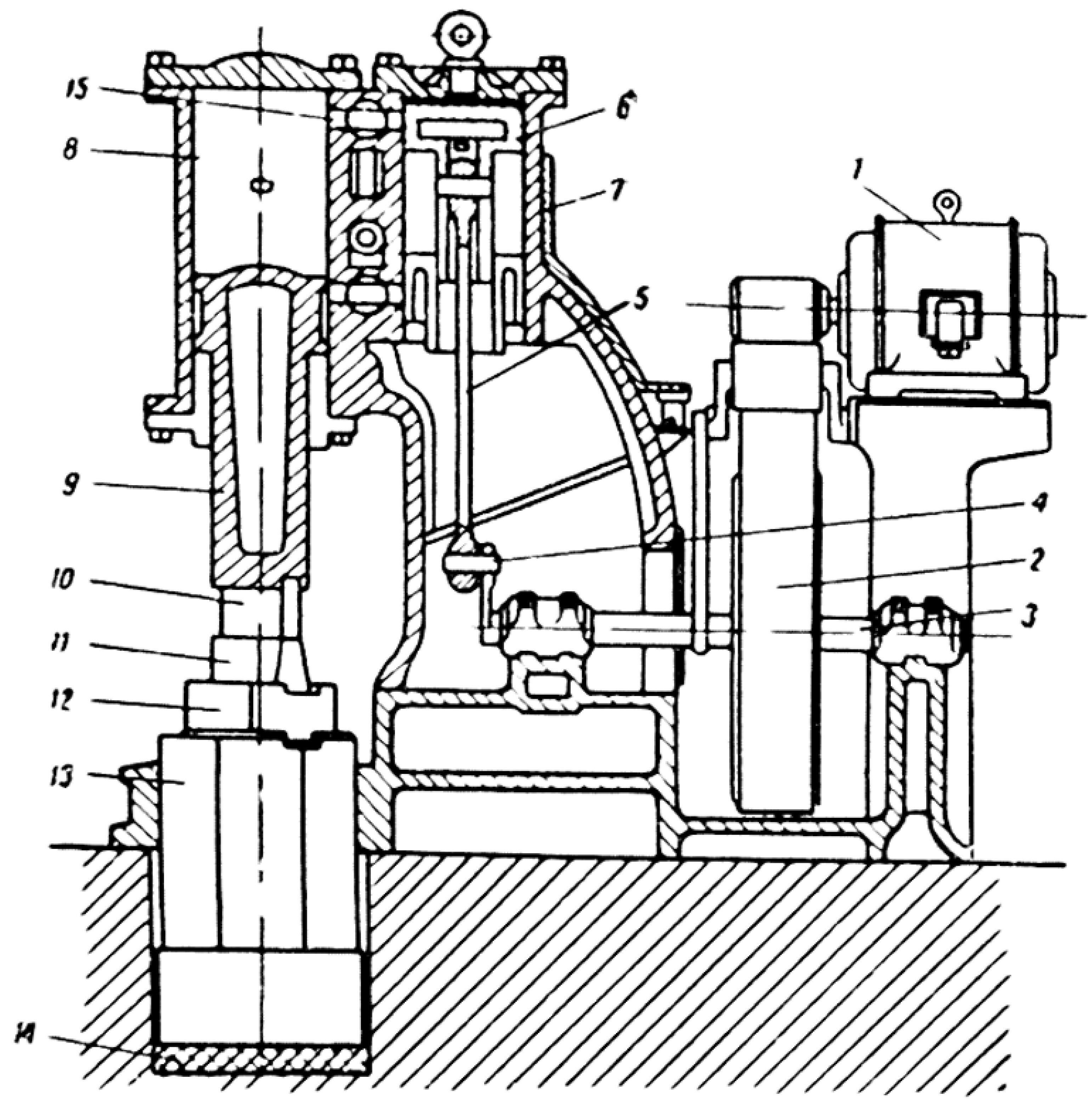


Fig. 148. Schematic section of a pneumatic hammer

shaft *3* the crank throw of which is located inside the hollow frame of the hammer. Movement is transmitted from journal *4* of the crankshaft with the aid of connecting rod *5* to piston *6* of air cylinder *7*. Piston *9*, cast integral with its heavy hollow rod, travels inside working cylinder *8*. The piston, together with its rod, acts as the ram of the hammer. The bottom end of the piston rod has a slit for securing top die *10*. The cylinders are connected by two channels.

Motion is transmitted from electric motor *1* through sheave *2*, crankshaft *4* and connecting rod *5* to piston *6*, which travels up and down. During the down-stroke of piston *6*, a partial vacuum is created above it. As this air cylinder communicates with the working cylinder through a channel, a partial vacuum will also be created in working cylinder *8* above piston *9*. On the other hand, during its down stroke, piston *6* of the air cylinder compresses the air below it, forcing it through the bottom channel into the working cylinder of the hammer; this causes the air to exert an upward pressure on piston *9* of the hammer, forcing the piston together with its piston rod to rise. During the reverse, i. e., upward, stroke, the piston

of the working cylinder compresses the air in the upper part of the cylinder and forces it through the upper channel into the working cylinder. At the same time, a partial vacuum is created under the working cylinder. The compressed air exerts a downward pressure on the piston of the hammer forcing it down, as a result of which the ram falls, i. e., strikes the forging. The piston of the air cylinder travels continuously up and down.

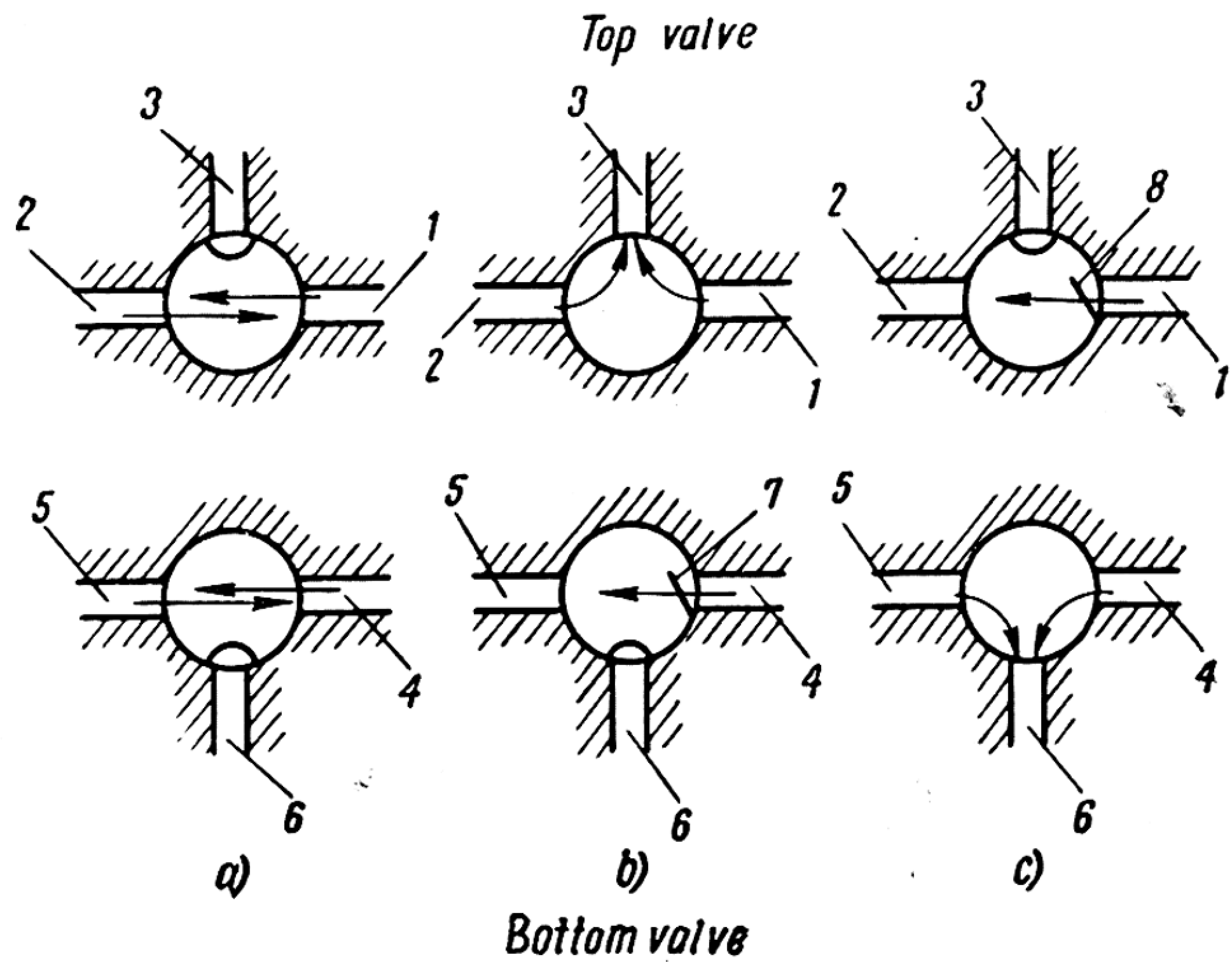


Fig. 149. Diagram of air flow in the valves of a pneumatic hammer

Anvil block *13* rests on a foundation and is supported by wood blocking *14*. The bottom die *11* is secured by keys in the slits of upper part *12* of the anvil block. The ram is raised and lowered with the aid of two rotary-type valves *15*, one of which is located in the upper channel and the second—in the lower channel. The valve comprises a cylinder with a channel machined in its centre. This cylinder rotates inside a bushing fitted with ports located so as to coincide with the channels in the cylinder.

Depending on the relative positions of the valve and the channels in the cylinder, the ram of the hammer can: 1) effect blows, i. e., alternately rise and fall; 2) remain suspended, or 3) be pressed against the forging. The corresponding positions of the valves are schematically shown in Fig. 149. The arrows in this figure indicate the direction of the air flow. If the valve is in the position shown in Fig. 149,*a*, then channels *1* and *4*, connecting the valves with air cylinder, and channels *2* and *5*, connecting them with the working cylinder, will be open while channels *3* and *6*, connecting the valves with

the outside atmosphere, will be closed. In this position, air will flow from the air cylinder to the working cylinder and back. The piston of the working cylinder and the ram secured to it will travel alternately up and down, striking the forging on the down-stroke.

If it is required to hold the ram in a suspended position, channel *3* of the upper valve is opened (Fig. 149,*b*) thereby releasing the air from the working and air cylinders. At the same time, channel *6* of the lower rotary slide valve, and channel *4* leading from the air cylinder are closed; channel *4* is closed by valve *7* which can open only inside the slide valve. When the air cylinder piston descends, the air beneath it will be compressed, opening valve *7* and will flow along channel *5* under the piston of the working cylinder. During the up-stroke of the air cylinder piston a partial vacuum will be created beneath it, and valve *7* will tightly close channel *4*. Thus, when the valves are in this position, air will flow only beneath the piston of the working cylinder; and as the air pressure increases with each stroke of the air cylinder piston, the piston of the working cylinder will ascend and remain in this position until the hammer operator changes the position of the valves.

If it is required to press the ram with considerable force against the forging, the rotary-type slide valve must be positioned as shown in Fig. 149,*c*. Here channel *3* is completely closed, and channel *1* is closed by valve *8* which, like valve *7*, can open only inside its valve. During the up-stroke of the air cylinder piston, the air beneath the piston will be compressed, open valve *8* and flow through channel *2* into the working cylinder. When the piston of the working cylinder falls the compressed air of this cylinder will close valve *8*; thus, during the up- and down-strokes of the air cylinder piston, air will be forced only into the space above the piston of the working cylinder, creating a high air pressure which will cause the ram to exert a great pressure on the forging.

The rotary-type valves are controlled by a hand lever or with the aid of a foot treadle. The force of the blow is controlled by a handle which adjusts the opening of the valve through a system of levers. The greater the required force of the blow, the further the handle must be turned (until it can go no further), so as to completely open the channels.

SPRING AND PNEUMATIC HAMMER MAINTENANCE AND OPERATION RULES

Before commencing operations, always:

1) Check the hammer for any damage or defects, and see that the top and bottom dies are properly secured and that the hammer is properly lubricated;

2) Remove all scale, grease and moisture from the faces of the top and bottom dies with a wire brush or broom;

3) Remove all tools, fixtures and other articles not directly needed for the execution of the work in hand;

4) See that the control gear and mechanism operate properly.

During operation:

1) Always keep the forging as close as possible to the centre of the die, as the hammer will wear more quickly, and the piston rod may break if work is done on the edge of the die;

2) Avoid, as far as possible, idle blows of the top die against the bottom die; heavy idle blows may lead to breakages;

3) Forge only well-heated metal;

4) See that the tongs are never caught between the dies; always hold the handle of the tongs sideways, and not directly in front of you;

5) Never attempt to clean, lubricate or repair the hammer before the ram has been lowered, the electric motor switched off and the hammer stopped. Never clean, lubricate or repair the hammer while it is in motion.

After the completion of work:

1) Always stop the hammer and lower the ram onto the anvil block;

2) Remove all tools, fixtures and forgings to their allotted places and clean the working place from all scale and cuttings;

3) Always report any trouble in the operation of the hammer observed during work to the shop maintenance foreman.

STEAM-AND-AIR HAMMERS

Steam-and-air hammers are most widely used in forging practice. They are so called because they can operate either on steam or on compressed air.

The steam-and-air hammer consists of a frame installed on a rigid foundation. A cylinder is firmly attached to the top of the frame. A piston travels inside this cylinder as in a steam engine; the piston is connected to a rod, to which a ram with a die at its lower end is fastened. Steam is let into the lower section of the cylinder, beneath the piston, thereby raising the piston rod together with the ram. When the valve is opened, the steam escapes from the cylinder, and the piston, together with the ram, falls onto the forging. The greater the height from which the ram falls, the greater will be the force of the blow.

Steam hammers are generally built with falling parts weighing 0.5, 0.75, 1.0, 2.0, 3.0, 5.0 and 7.0 tons. However, steam-and-air

hammers with falling parts weighing 25, 50, 75, 100 and 150 kg are also employed.

Steam-and-air hammers are divided into single- and double-action hammers. In *single-action* steam hammers (Fig. 150) ram *1* is attached to piston rod *2* and travels along guides *8*. Piston *3* travels inside cylinder *4*. Steam is delivered to the cylinder from the steam line

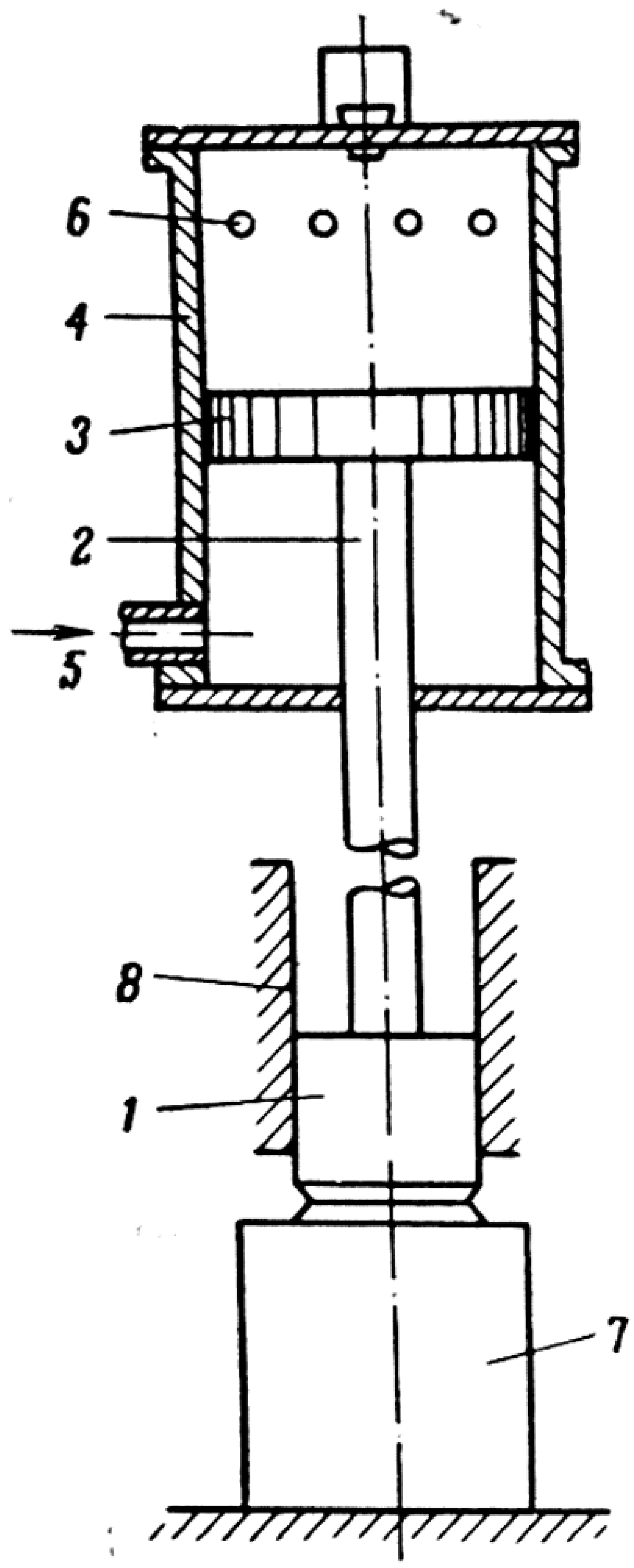


Fig. 150. Single-stroke air-and-steam hammer diagram

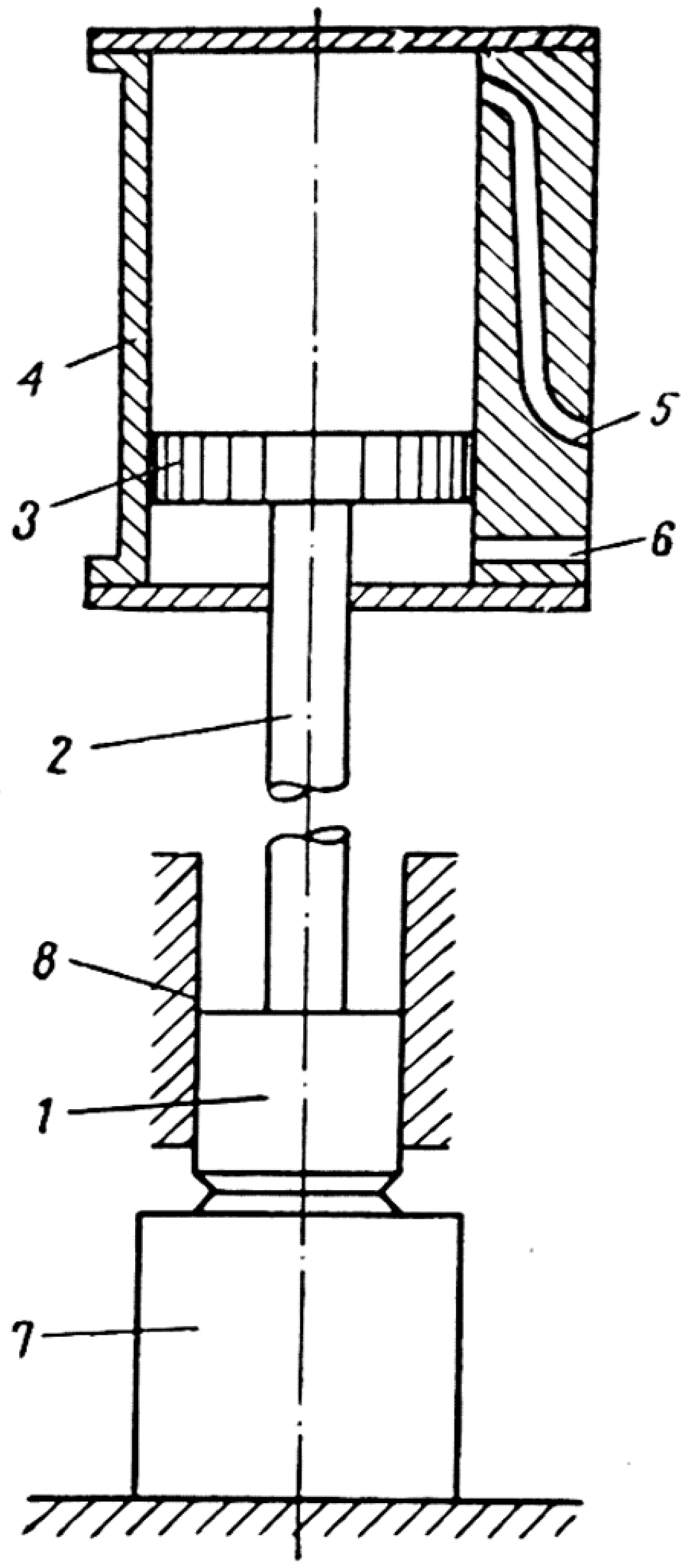


Fig. 151. Double-stroke air-and-steam hammer diagram

through inlet *5*, thus raising the piston and the ram connected to it. The steam is cut off after the ram has risen to a sufficient height, and escapes through port *5*. The ram falls under its own weight and strikes the forging on anvil block *7*. Located in the upper section of the cylinder are several ports *6* designed to slow down the speed of the piston as it reaches its upper position. It is slowed down as follows: as it ascends, the piston closes these ports and compresses the remaining air in the upper section of the cylinder which acts as a buffer. Single-action steam hammers are seldom built nowadays.

Double-action hammers (Fig. 151) differ from single-action hammers in that the steam is employed both for raising ram *1* and for increasing the force of its impact against bottom die *7*. This is done by letting steam into the space above the piston as the ram is lowered. During the down-stroke of rod *2* and piston *3* steam is delivered into cylinder *4* through channel *5* and exerts a downward pressure on the piston. During the up-stroke of this piston steam enters through channel *6* and forces the piston downwards. At the same time, the steam above the piston escapes through channel *5*.

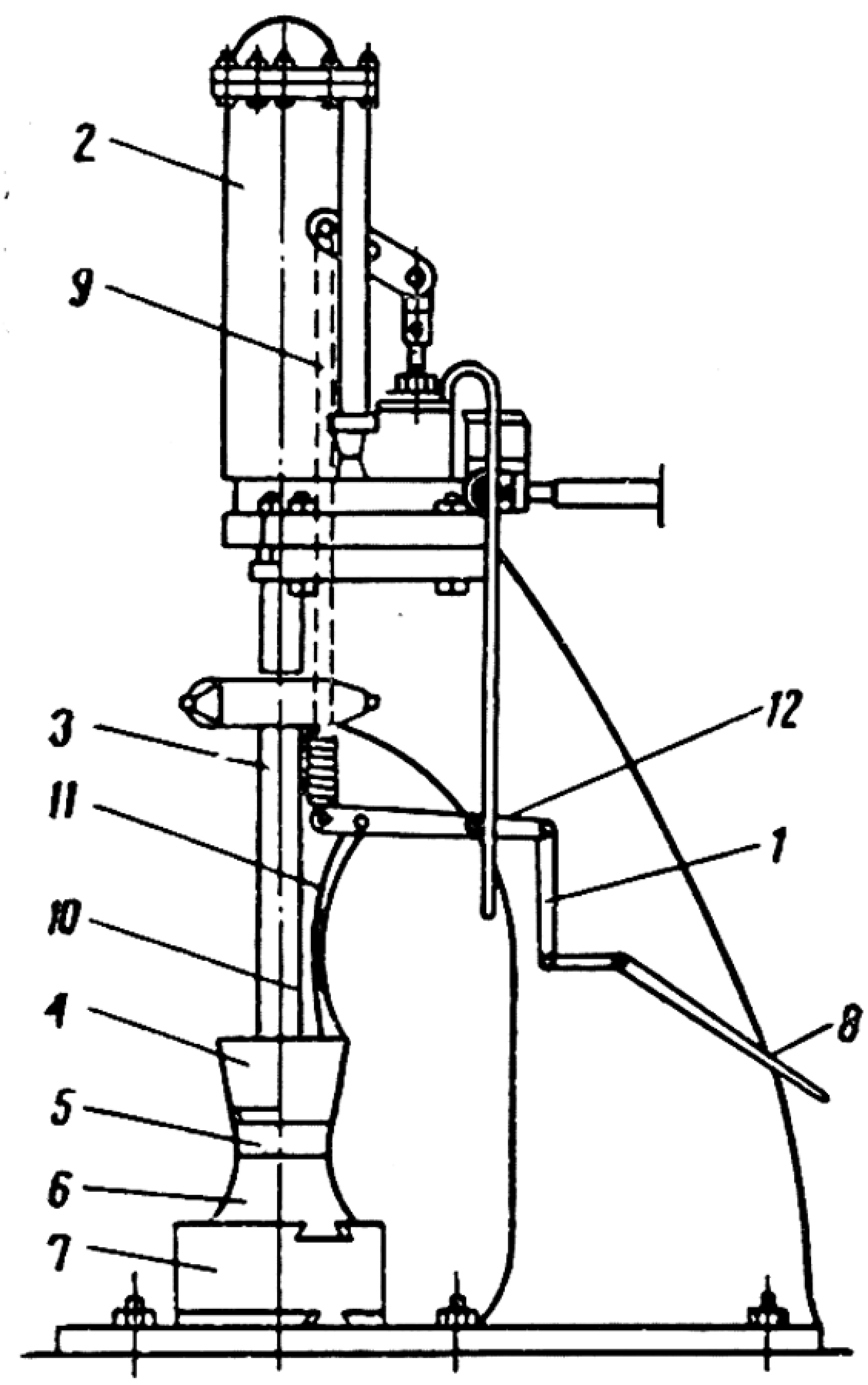


Fig. 152. Single-frame hammer, without guides

Steam-and-air hammers designed for hammer forging are classified into *four types*, each differing in the design of the frames and the number of guides.

Single-frame hammers, without guides. These hammers, as can be seen from Fig. 152, are built with a single frame *1* on the top of which is bolted steam cylinder *2*. In this cylinder travels the piston with its rod *3*, ending in ram *4* to which is keyed top die *5*. Bottom die *6* is keyed to anvil block *7*.

The hammer is equipped with a special steam delivery mechanism called the *steam distributor*. Steam is delivered to the top or bottom of the piston, depending on whether the ram is to be raised or lowered.

The steam distributing mechanism is shown in Fig. 153. Steam is delivered through channel *5* and discharged along pipe *6*. Rotary valve *2* is shaped like a hollow cylinder, diameter of its central section being less than that of its ends. Fig. 153 shows the valve positioned in such a manner as to enable steam to escape from channel *4* through the inner chamber of the rotary valve into pipe *6* and thence into the atmosphere. The central, narrower section of the valve connects channel *3* with channel *5*; hence, fresh steam will be delivered through channel *5* beneath the piston of the cylinder. Thus, the piston in cylinder *1* will be pressed downwards by fresh steam under a pressure of 6-8 atmospheres. The piston in cylinder *1* will not be subjected to this downward pressure of steam, and therefore will rise, taking with it the piston rod and the ram together

with its die. If the valve is moved upwards, channel *3* will communicate with pipe *6* and the steam beneath the cylinder will escape, while channel *4* will be closed by the central (narrower) section of the valve, thus communicating with the fresh steam channel *5*. This will result in the space above the piston being filled with steam, which will force the piston downwards; the piston, together with the ram, will commence to fall, thus delivering the required blow.

Fresh steam is delivered along the pipe; before it can flow into the slide valve chest, it flows through gate *7* designed to disconnect the cylinder of the hammer from the steam inlet piping. The gate consists of a cylindrical valve, which is held by a spring against the inner cylindrical surface of its chamber. When this valve closes channel *5*, the pressure of the spring is increased by the pressure of the steam, the valve will be pressed more closely to the surface of the chamber and, consequently, will cut off the steam supply more reliably. Frequently stop valves are installed instead of gate valves to cut off the supply of steam.

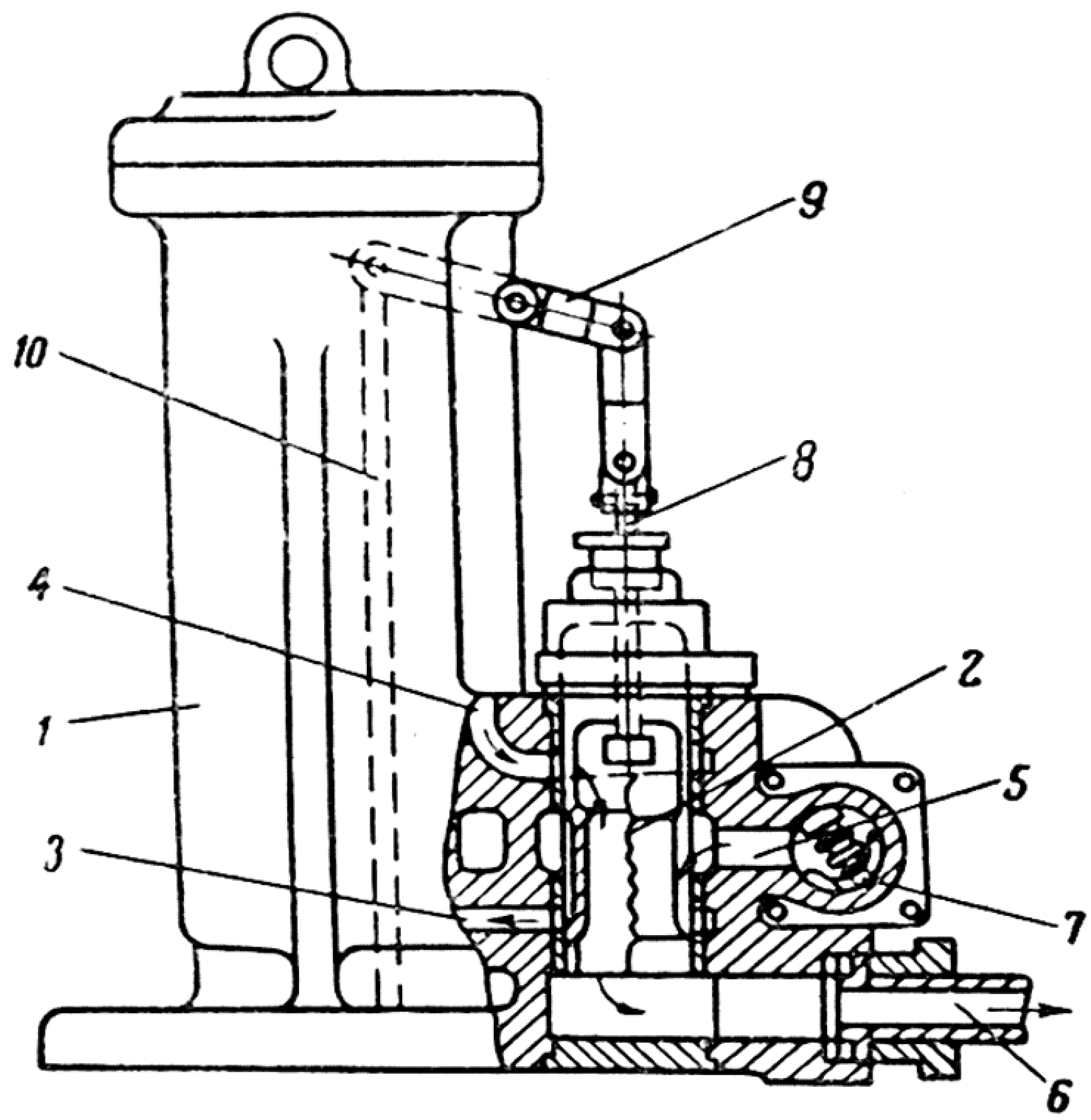


Fig. 153. The steam distributing mechanism of the hammer shown in Fig. 152

Let us return to Fig. 152. In steam hammers, the rotary valves can be moved either by hand or automatically. Manual control is effected with the aid of handle *8* connected to rod *9* by a system of levers. (Fig. 153 shows valve rod *8* connected to the slide valve.) Automatic control of this valve is effected with the aid of curved lever *11* attached to equaliser *12*; when handle *8* is disconnected, lever *11* thrusts against horn *10*, which is attached to the ram of the hammer. By this arrangement, horn *10*, when the ram travels up and down, will rotate curved lever *11* thus causing equaliser *12* to swing up and down, forcing rod *9* likewise to move up and down, and rod *9* to move the valve. (In Fig. 153 the equaliser is numbered *9* and the rod—*10*.) This mechanism can transmit various motions to the valve and thus ensure a wide range of hammer blows from the heaviest to the lightest.

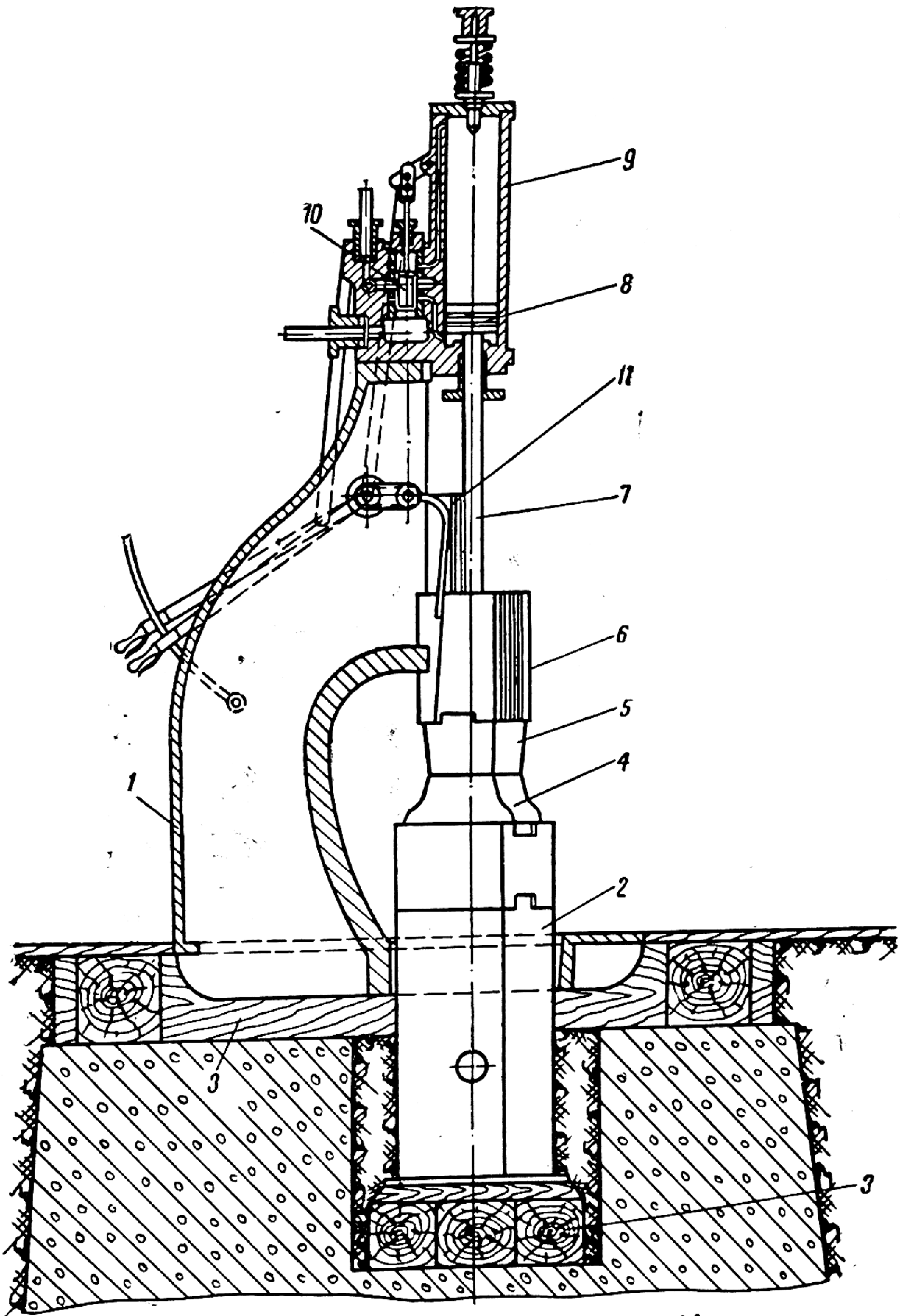


Fig. 154. Single-frame hammer, with guides:

1) frame; 2) anvil block; 3) wooden support; 4) bottom die; 5) top die; 6) ram; 7) piston rod; 8) piston; 9) cylinder; 10) rotary-type slide valve; 11) guides

The hammer described above is built without ram guides, and is for this reason called a single-frame hammer without guides. The absence of ram guides permits unhampered forging; the work

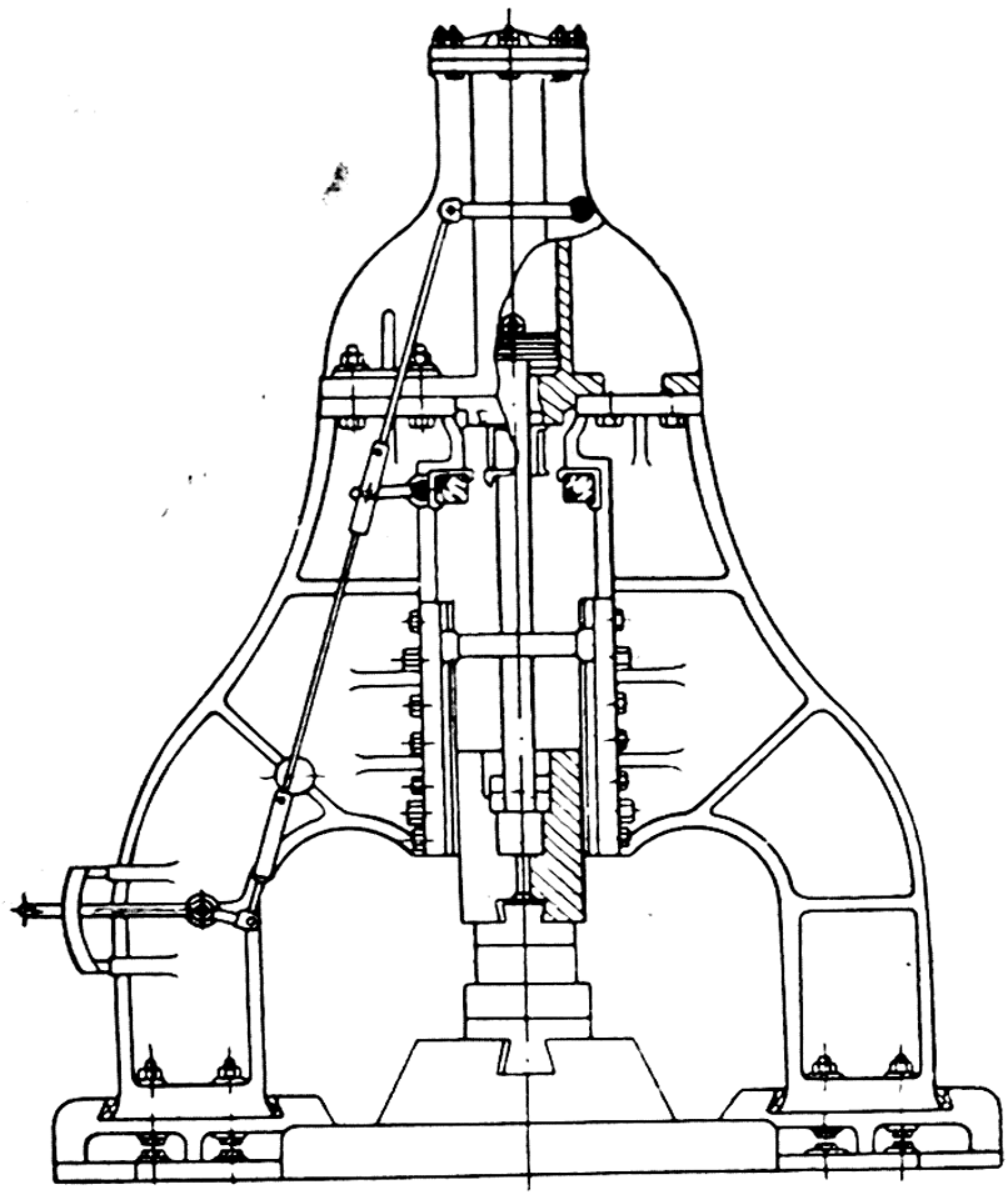


Fig 155. Double-frame 2-ton steam hammer

can be approached from three sides. These hammers are very convenient for repair jobs. Their disadvantage is that, when delivering eccentric blows, the stuffing box, piston rod and cylinder are liable to break.

Single-frame hammers with guides. Fig. 154 shows the cross-section of a single-frame hammer with guides. In these hammers the cylinders very seldom break, as the horizontal forces resulting from off-centre (eccentric) blows are taken up by the guides and are imparted only in a very insignificant degree to the stuffing box, rod and cylinder. They do not, however, possess the advantages to be found in single-frame hammers without guides: work on these hammers is hampered by the guides which, moreover, limit the size of the work to be forged. Single-frame hammers with guides are chiefly employed for reducing (drawing) operations and for forging in bolsted dies.

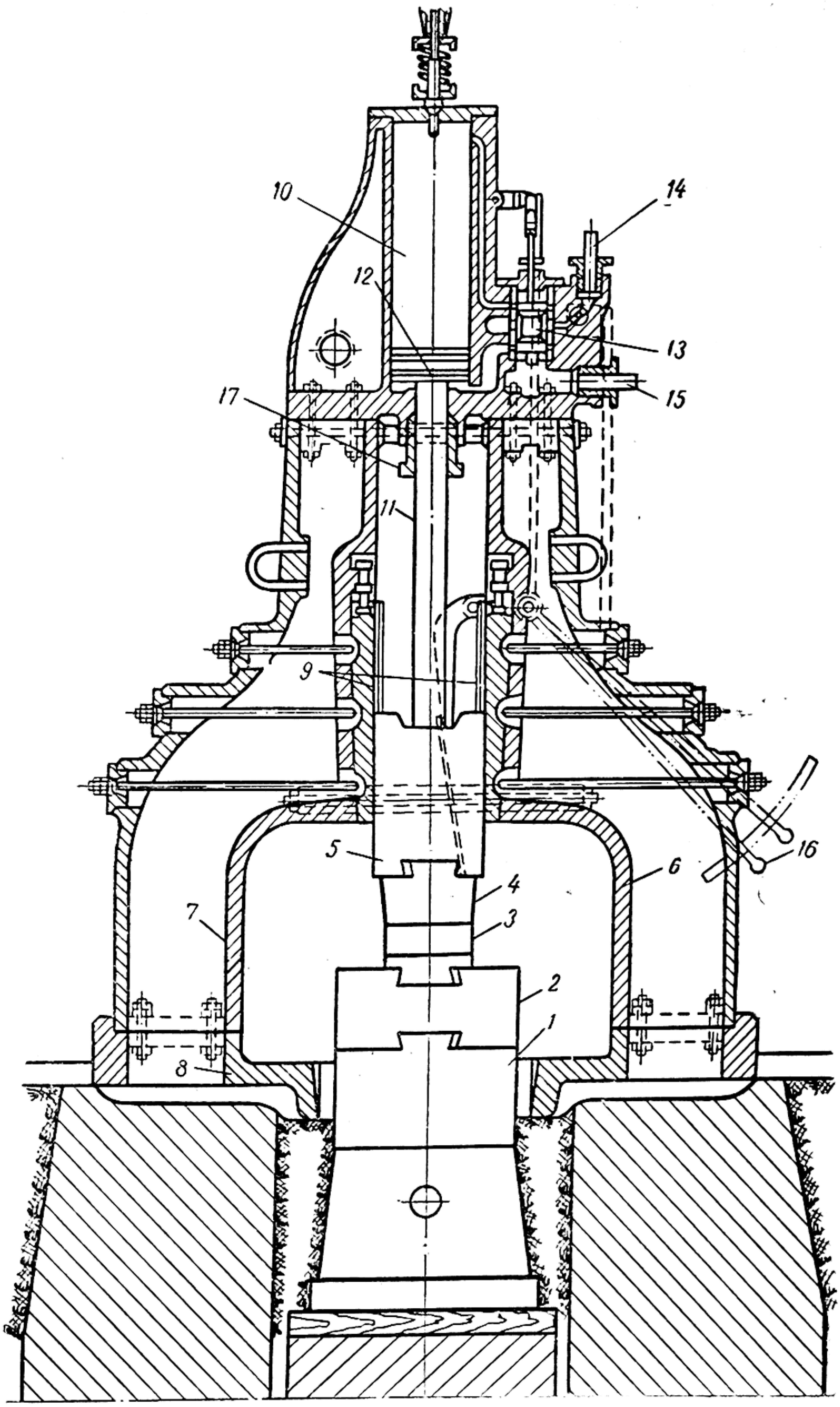


Fig. 156. Section of double-frame 2-ton steam hammer:
1) anvil block; 2) pillow; 3) bottom die; 4) top die; 5) ram; 6) RH frame; 7) LH frame; 8) foundation plate; 9) guides; 10) cylinder; 11) piston rod; 12) piston; 13) slide valve; 14) live steam inlet pipe; 15) steam return pipe; 16) slide-valve mechanism lever; 17) stuffing box

The hammer is erected on a concrete foundation; anvil block 2 and frame *1*, however, are not installed directly on the concrete, but on wooden beams *3*. These beams serve as shock absorbers, which protect the concrete foundation from rapid destruction through the vibration caused by the blows.

Single-frame hammers with guides are usually built with falling parts weighing from 250 to 1,000 kg, and, more rarely, with falling parts weighing up to 2,000 kg.

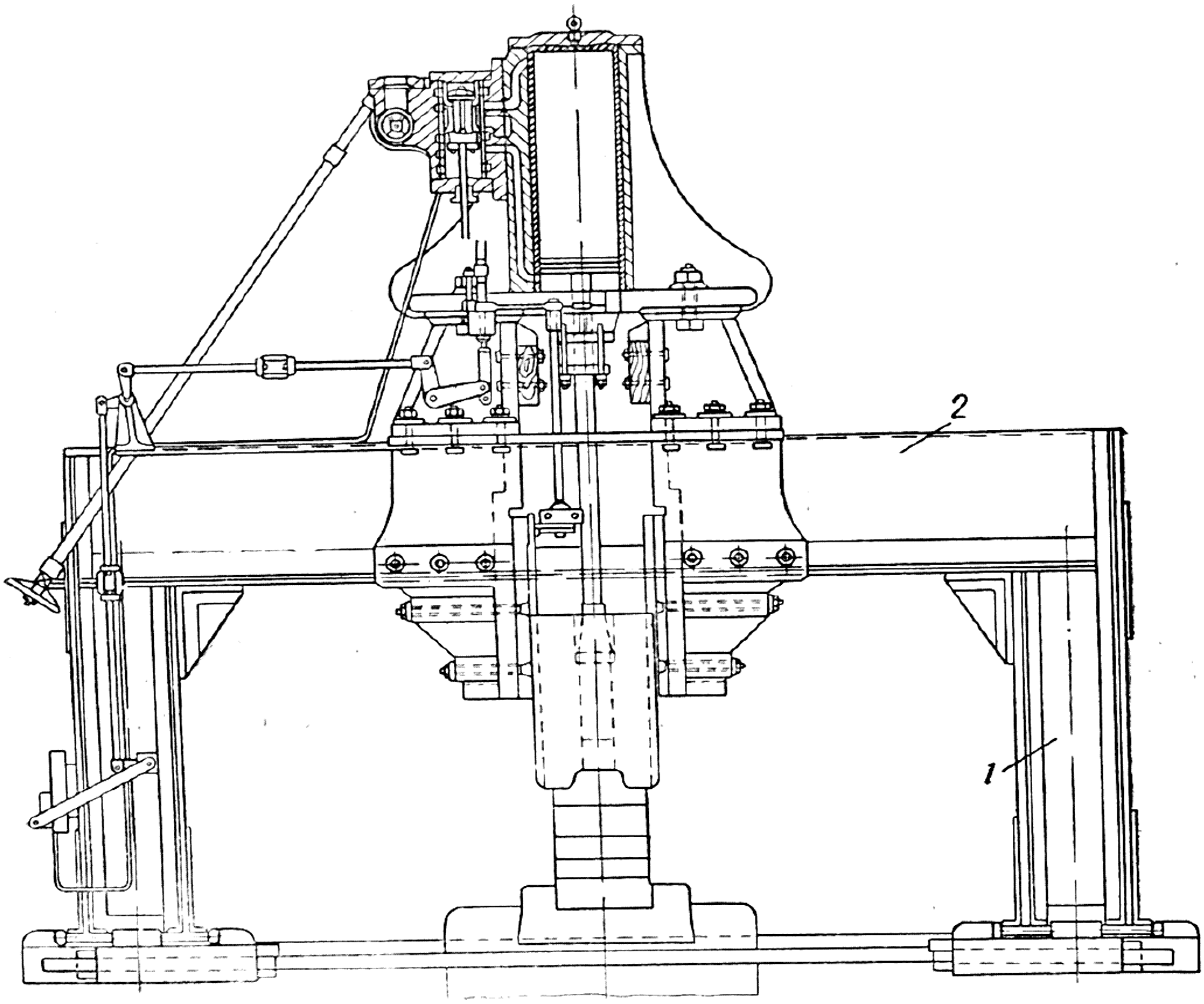


Fig. 157. Double-frame bridge-type steam hammer

Double-frame steam-and-air hammers are built in two designs: arch- and bridge-type hammers.

Arch-type double-frame hammers. The general view of a double-frame hammer of this type is shown in Fig. 155; Fig. 156 gives the longitudinal section of such a hammer. The frames for these hammers are of cast steel and shaped like an arch; the cylinder is installed between the frames.

Arch-type double-frame hammers are widely used. The cylinder and slide valve chest of these hammers are not liable to displacement as a result of heavy blows, neither are they liable to get out of alignment.

Arch-type double-frame hammers permit the work to be approached only from two sides (from the front and from the rear); this is not very convenient for making complicated and heavy forgings. Arch-type hammers are built with falling parts weighing from 1 to 5 tons.

Bridge-type double-frame hammers. Fig. 157 shows the diagram of a bridge-type double-frame hammer. The frame of such a hammer is usually built from two rivetted or welded posts *1*, to which is rivetted or welded a cross-beam *2*. The dimensions and weight of such hammers are much greater than those of arch-type hammers.

The chief advantage of bridge-type hammers compared with arch-type double-frame hammers is that they allow the blacksmith to approach the work from any direction, thus permitting their use for forging a wide variety of intricate work and, chiefly, for making heavy and large forgings. These hammers are built with falling parts weighing from 1 to 5 and even 7 tons, but more frequently, from 3 to 5 tons.

HAMMER FOUNDATIONS AND ANVIL BLOCKS

The *foundation* is one of the most important parts of a hammer. During the operation of a forging hammer, only a part of the energy of the blow is utilised in deforming the forging. The remaining energy of the hammer blow is transmitted through the bottom die and anvil block to the foundation. Besides this, the foundation serves as

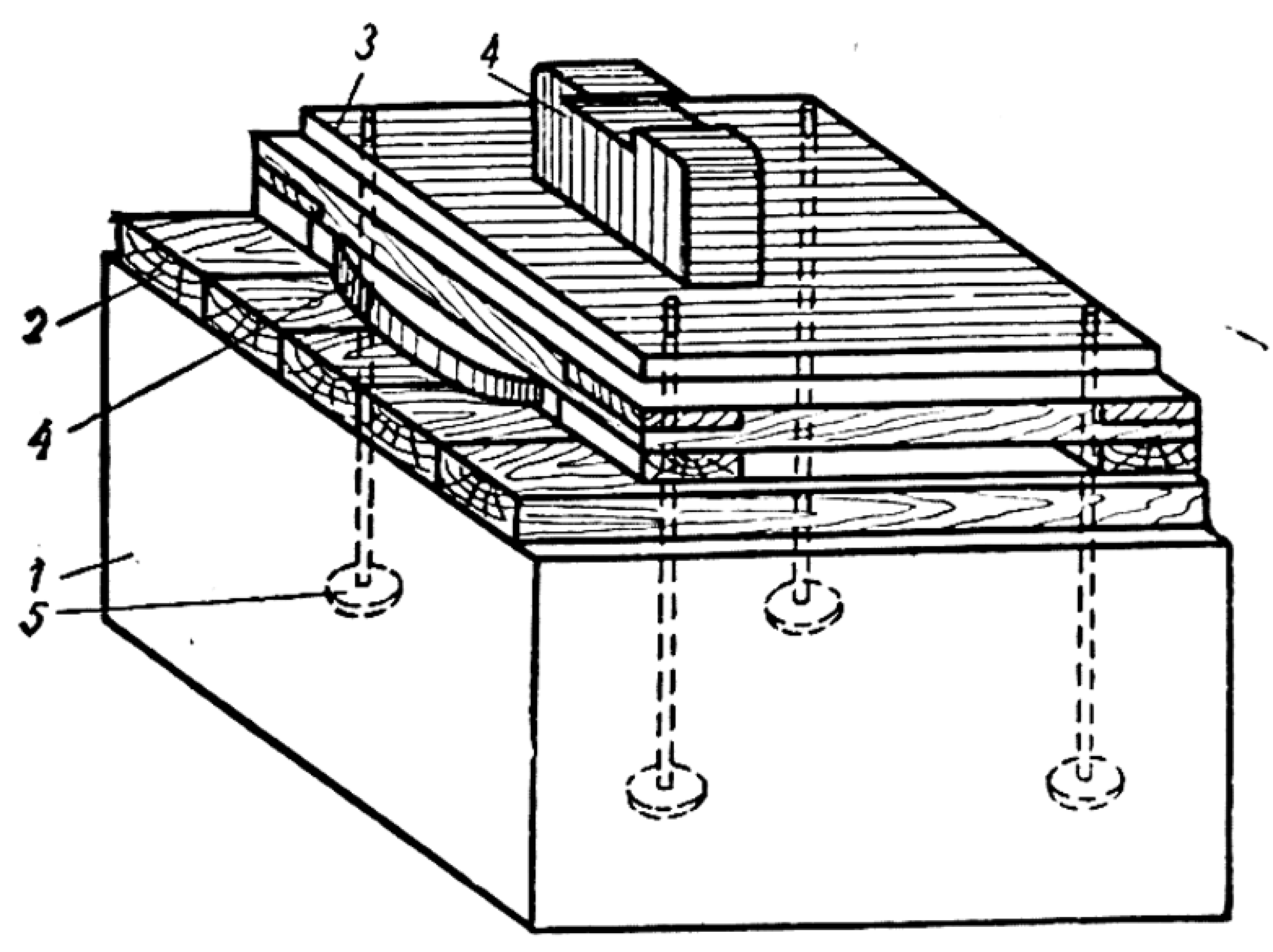


Fig. 158. Single-frame hammer foundation:
1) reinforced concrete foundation; 2) wooden beams; 3) hammer foundation plate; 4) anvil block; 5) foundation bolt

a support for the hammer. The greater the weight of the falling parts of the hammer, the heavier must be the foundation.

Weak foundations lead to the poor utilisation of the energy of the hammer blows for deforming the forging. Moreover, each blow sets up vibrations in the soil and foundation, which may be transmitted to the hammer frame and result in its breakage.

Hammer foundations are generally made of reinforced concrete. In single-frame hammers, the anvil block and the foundation plate to which the frame is secured rest on a common foundation (Fig. 158).

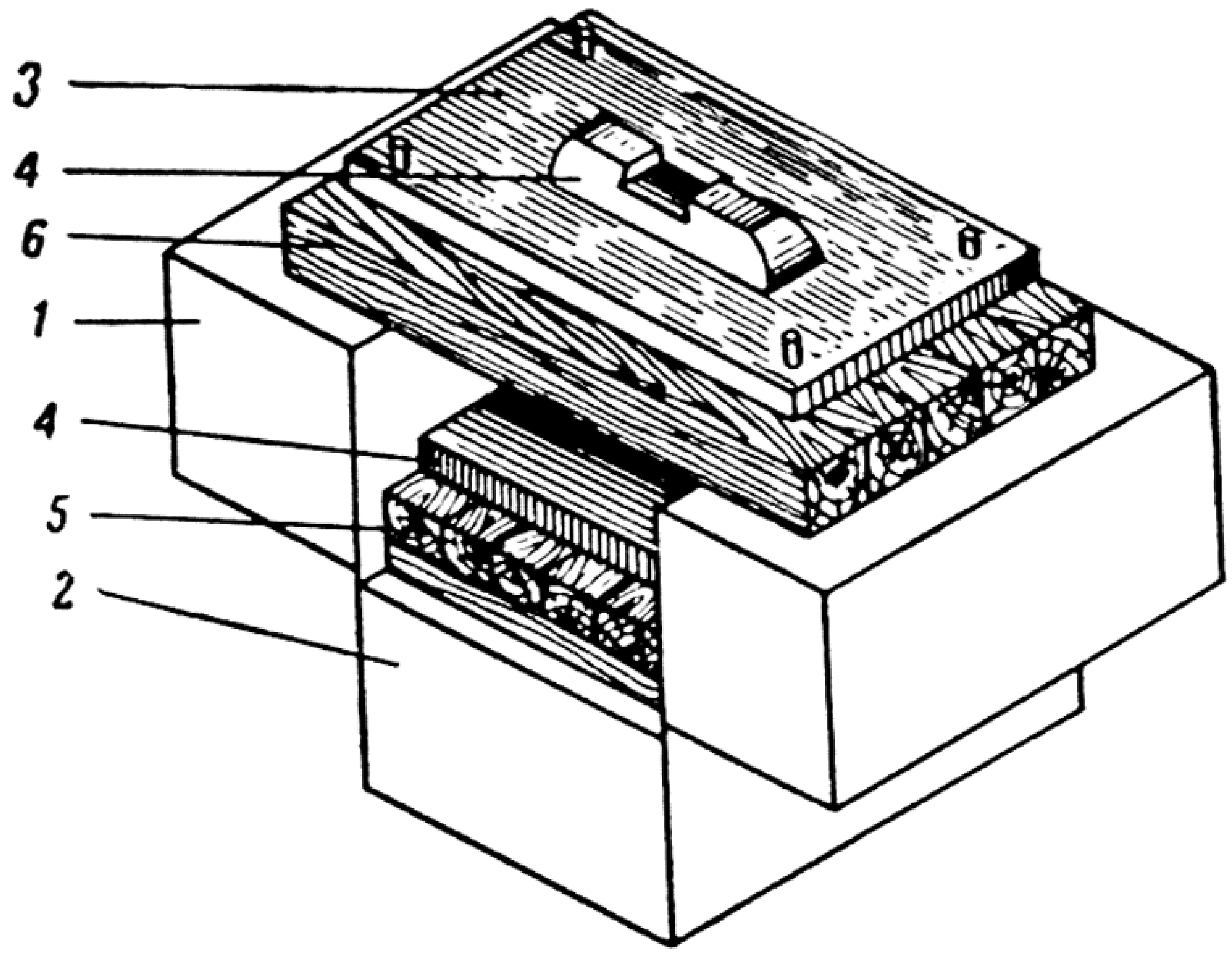


Fig. 159. Foundation of two sections for double-frame steam hammer

Double-frame hammers of the arch and bridge types are usually erected on foundations consisting of two independent sections (Fig. 159). Section *1* is designed for installing foundation plate *3*, to which the hammer frame is secured, while anvil block *4* is mounted on foundation *2*. Wooden beams *5* and *6*, usually made of oak or any other deciduous timber, and bolted together, are inserted under the anvil block and foundation plate to dampen the blows of the hammer.

The *anvil block* comprises a massive steel casting with a mortise on its top for securing the bottom die. The anvil block absorbs the energy of the hammer blow, which is transmitted from the forging to the bottom die and thence to the anvil block. If the latter is not sufficiently heavy it will rebound under the impact of the hammer blow, thus reducing the force of the blow and even resulting in the damage or breakage of the hammer.

Hammers of light capacity are usually built with cast-iron anvil blocks. The anvil blocks of heavy hammers are of steel and made in sections, which are secured to each other with dovetails *3* and keys

4 (Fig. 160). *Built-up anvil blocks* are not so efficient as solid anvil blocks, but they are easier to manufacture and to handle.

To reduce the pressure on the foundation, the cross-sectional area of the shoe *1* of the anvil block is made greater than that of its upper

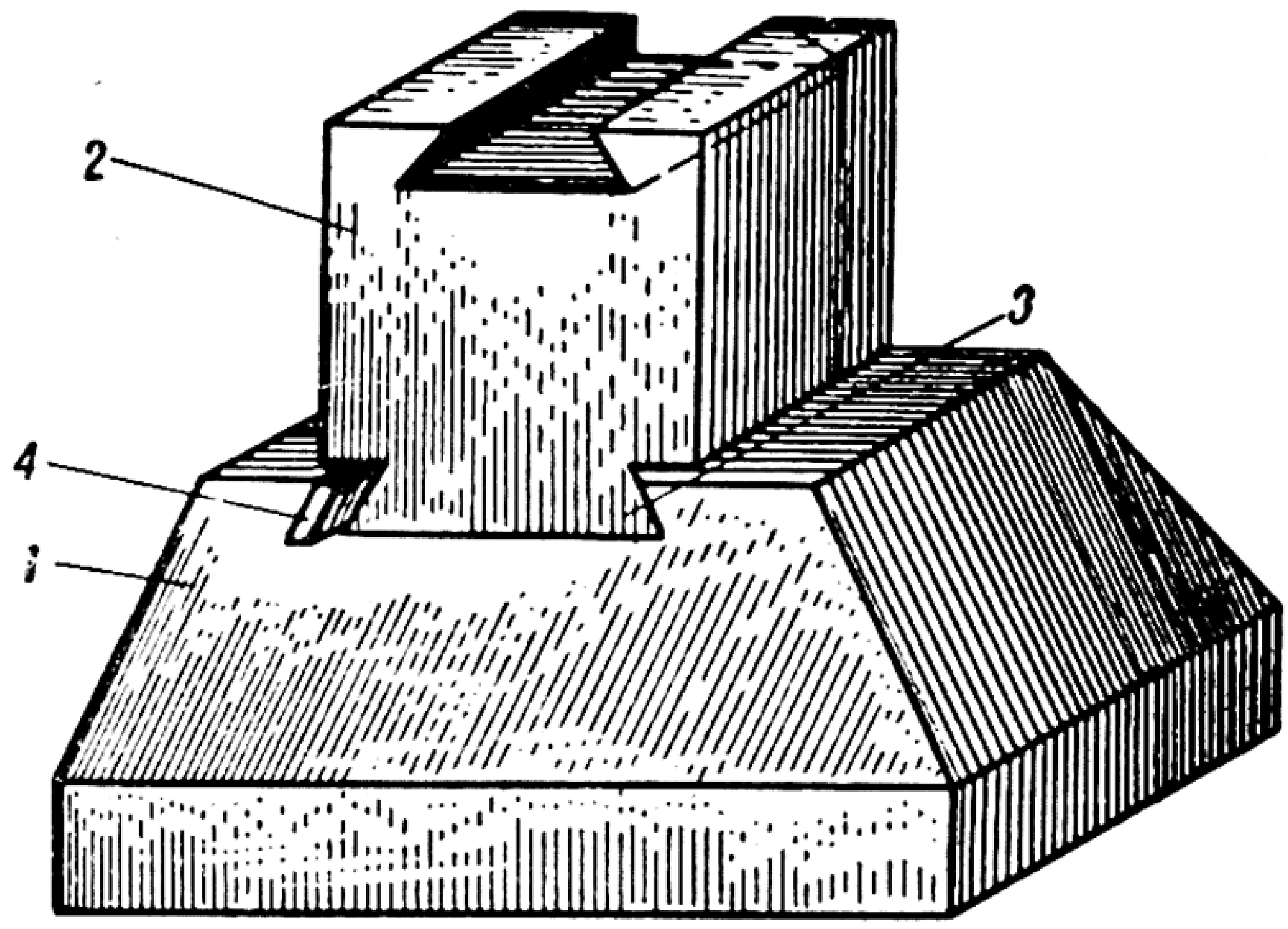


Fig. 160. Built-up anvil block

section *2*. Its top and bottom surfaces must be machined smooth to ensure close contact with the wooden beams under it, and with the dovetail of the bottom die on top. The anvil block should weigh, as a rule, from 15 to 20 times as much as the falling parts of the hammer.

STEAM DISTRIBUTION AND CONTROL OF STEAM HAMMERS

In steam hammers the steam is most commonly distributed with the aid of a simple rotary-type valve (see Fig. 153).

Depending on the control system, hammers with rotary-type valve steam distribution are classified as: 1) hand controlled, 2) automatically controlled and 3) combined-control hammers.

Fig. 161 gives a diagram of a *manually controlled hammer*. Steam flows from the steam line through steam inlet into throttle chest *3*. On turning handle *6* throttle *4*, mounted on spindle rod *5*, will also turn, opening the port connecting valve chest *2* with throttle chest *3*. The steam, flowing through this opening, enters the annular space in the central section of rotary valve *7*. The rotary valve can only travel up or down when actuated by valve rod *8* and lever *9*. In doing so, the slide valve will open the upper and lower ports of the valve jacket, which are connected by channels *10* and *11* to the top and bottom of cylinder *1*. The piston, together with the piston rod and the ram, will rise or fall, depending on the position of the rotary valve.

In the position illustrated in Fig. 161, when lever *9* is pushed upwards, the steam will flow from the central annular space of rotary valve *7* along channel *10*, under piston *12* and, on expanding, will force the piston and piston rod *13* upwards, together with ram *14*. The exhausted steam above the piston will escape through channel *11* into the exhaust pipe.

When lever *9* is depressed, the rotary valve will travel upwards. The steam from the central annular space of valve *7* will then flow through channel *11* into the upper part of the cylinder above the piston. The piston together with the piston rod and ram will be forced downwards, thereby causing the ram to strike the forging. The exhaust steam will be discharged from beneath the piston through channel *10* into the valve chest and, through the openings in the valve, into the steam exhaust pipe.

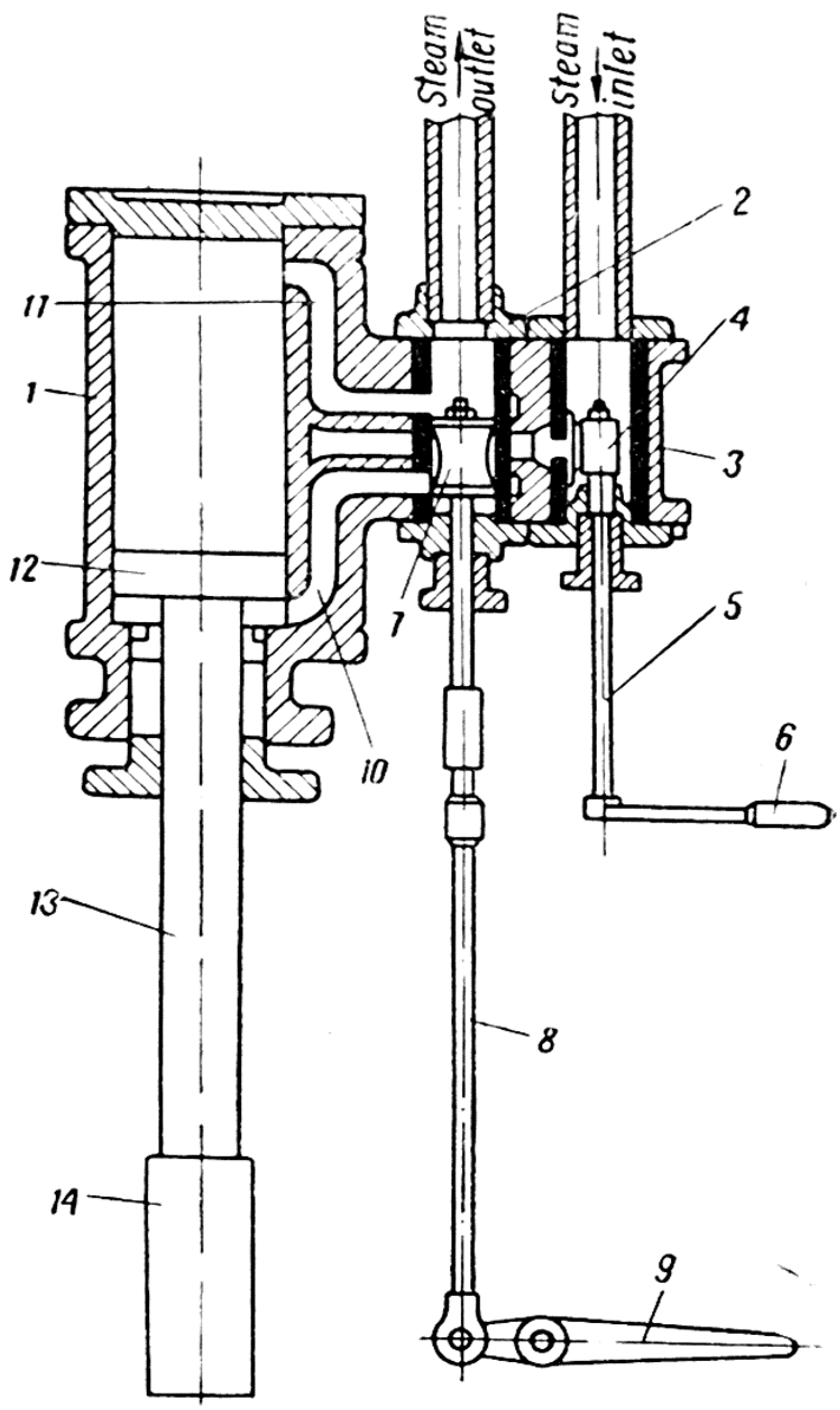
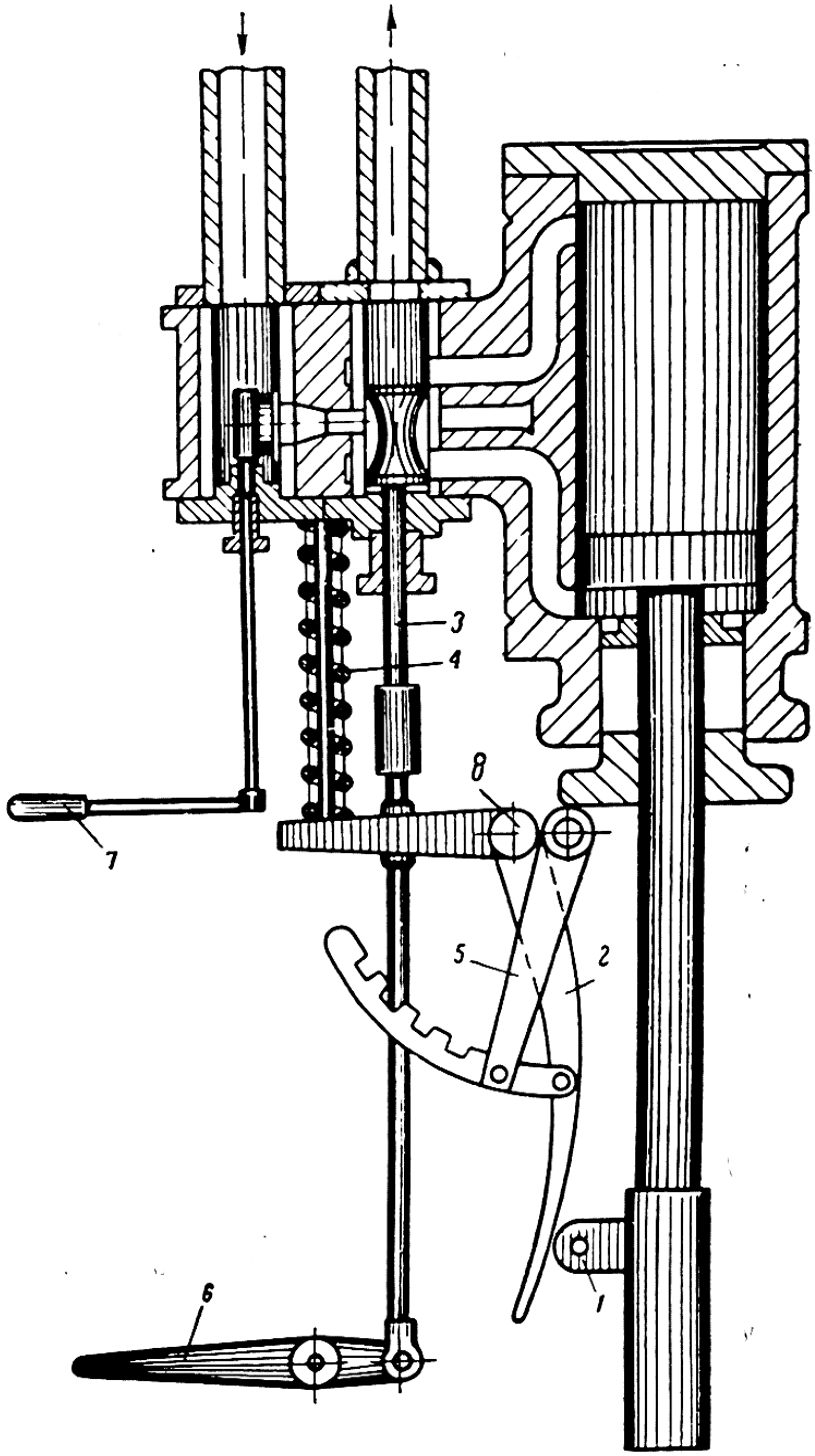


Fig. 161. Manual control diagram

Fig. 162 shows the diagram of *automatic steam distribution* in a steam hammer. The ram of the hammer has a roller *1* which, as the ram travels up or down, presses against curved lever *2* connected with the rotary valve. This lever is pivoted at point *0*, which can be adjusted as desired. Valve *3* is connected to the short horizontal section of lever *2*, which is always pressed against the roller of the ram by spring *4*. By turning handle *5*, the position of the centre of rotation (point *0*) of the curved lever can always be changed, thereby regulating the length of the stroke of the ram. During its upstroke, the ram pushes the lever, thereby displacing the valve upwards. This causes steam to flow from the valve along the channels into the top section of the cylinder, forcing the piston down. Lever *2* under the pressure of spring *4*, gradually resumes its former position, and steam



Fig, 162. Steam hammer automatic control diagram

flows under the piston and once more forces the ram upwards, etc.

Automatic distribution of the steam is effected in this manner. Hammers equipped with automatic steam distribution gear can

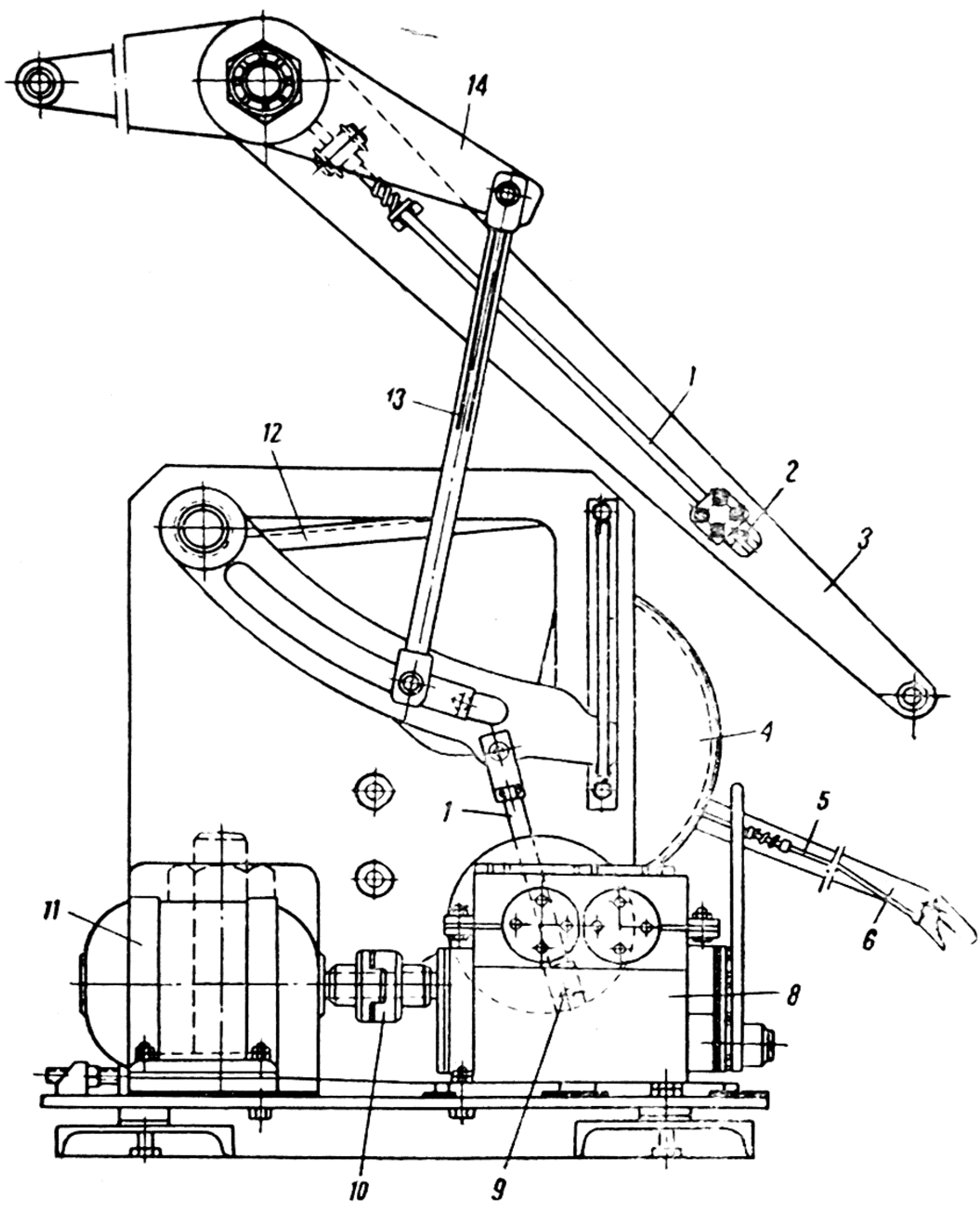


Fig. 163. Mechanism of steam hammer automatic control

also be manually operated with the aid of levers *6* and *7*; in this case, the steam distribution will be effected as shown in Fig. 161.

Heavy hammers employed for hammer forging are also sometimes equipped with *automatic control mechanisms*. Such a mechanism consists of the following chief units: electric motor *11*, reductor *8* and a system of links (Fig. 163). The reductor is connected to the electric motor through jaw-clutch *10*. Crank *9* which is connect-

ed to the link mechanism through rod *7* is mounted on the shaft of the reductor. The motion of the link mechanism is transmitted to the valve rod through rod *13* and lever *14*. To operate the hammer automatically, the electric motor must be switched on; rack lever

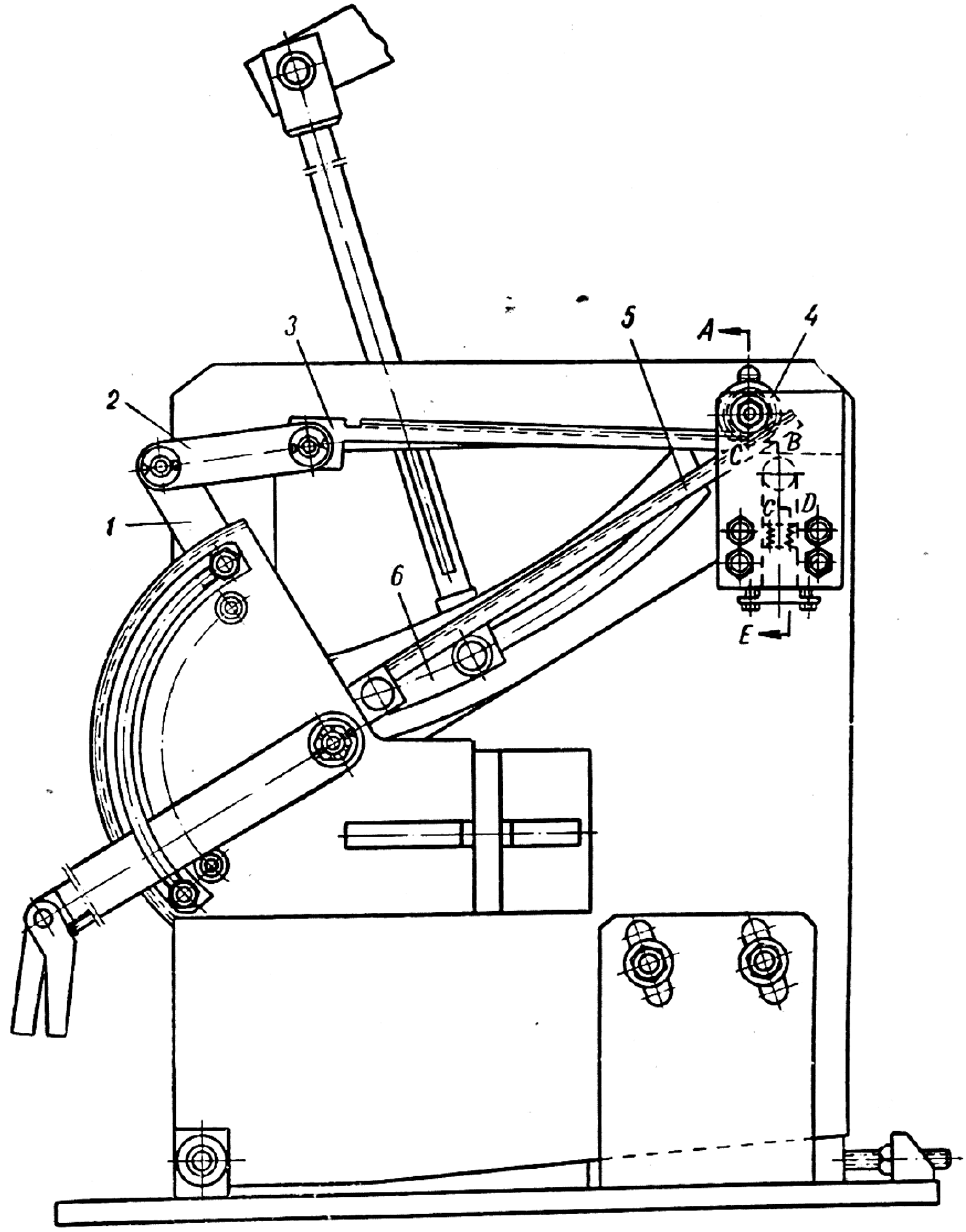


Fig. 164. Automatic control crank-type mechanism

5 is released with the aid of handle *6* and inserted in the required position in toothed sector *4*. The manual control is switched off by turning handle *2* clockwise, thereby releasing lock *1*.

When handle *6* is pulled upwards, the force of the blow of the ram will be reduced. This is due to the fact that the length of the arm of

the link is shortened, because rod *13* is moved towards the centre by lever *3*, gear *4* and rack lever *5* which is connected to lever handle *6*. On the other hand, when handle *6* (see Fig. 164) is depressed, the force of the blow of the ram will be increased. The force of its blow can also be increased or lessened by adjusting the length of crank *9* by inserting pin *12* in the corresponding hole in the crank (see Fig. 163).

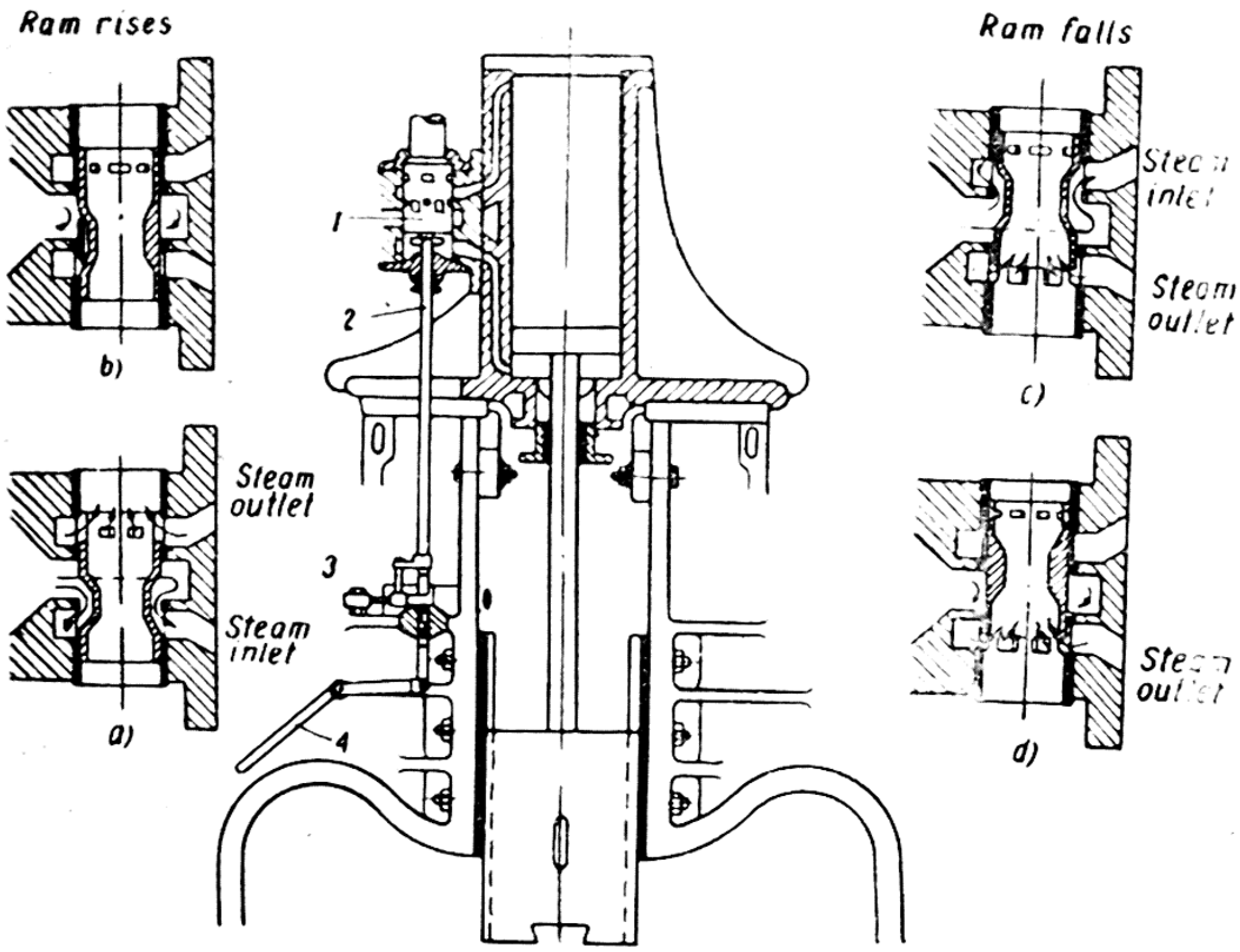


Fig. 165. Combined steam distribution diagram

This mechanism permits regulating the force of the blow of the hammer, and speedy transition from automatic to manual control, and vice versa, as desired.

Steam can be economised when raising the ram by not completely filling the bottom section of the cylinder with steam. The steam entering the bottom section of the cylinder must be cut off in time by skilful manipulation of the slide valve; this will ensure the further upward travel of the ram as a result of the expansion of the steam. If it is required to hold the ram in a suspended position, small portions of steam should be discharged at short intervals into the lower part of the cylinder, because steam, on condensing, contracts in volume, thus permitting the hammer to drop. Should it be necessary to squeeze the forging between the dies, the upper half of the cylinder must be completely filled with steam. In this case, the pressure of the weight

of the falling parts of the hammer on the forging will be increased by the pressure of the steam on the head of the piston. Automatic control is recommended for ensuring heavy and frequent blows.

As regards the degree of utilisation of energy, steam hammers are far from being perfect machines. Their efficiency is exceedingly low. In order to increase the efficiency of a hammer (i. e., to reduce the steam consumption), so-called *combined steam distributors* fitted with economic rotary valves are employed.

Fig. 165 shows the scheme of a combined steam distributor, employing a cylindrical rotary-type valve (a so-called piston valve). Valve *1* having several ports in its head and slits in its central section, is located in the valve chest of the steam cylinder and is connected to lever *4* by rod *2*. The valve can be vertically adjusted by moving the end of lever *4*. Simultaneously, the valve can be rotated with the aid of a special mechanism *3*.

In order to lift the ram, steam must be delivered below the cylinder piston.

For this purpose, control lever *4* must be raised, thereby causing the valve to descend, and its ports to come to the position, shown in Fig. 165, *b*. Steam will then enter under the piston and the ram will commence to rise. The steam in the upper half of the cylinder (above the piston head) will be discharged through the channel in the cylinder and the valve ports into the steam exhaust line. After the valve has risen and the piston has made approximately half its stroke, automatic mechanism *3* rotates the valve, thereby closing the lower steam outlet channel and cutting off any further delivery of steam beneath the piston or, in other words, the steam will be cut off. At this moment the valve will be in the position shown in Fig. 165, *a*. The steam, now in the lower half of the cylinder, will expand and continue to force the piston upwards and, with it, the ram of the hammer. Inasmuch as the further delivery of steam has been cut off half way through the upstroke of the piston, its consumption will be less than if the valve had been open until the ram reached its extreme top position.

To deliver a blow with the ram, the control handle *4* must be turned downwards. This will cause the rotary valve to rise to the position shown in Fig. 165, *c*, in which fresh steam enters into the upper part of the cylinder (above the piston) and forces the piston, together with the ram, to travel downwards rapidly and strike the forging. At the same time, the steam will escape from the bottom part of the cylinder through the lower channel and the valve chamber into the steam exhaust line. During the downward stroke of the ram of the hammer, automatic control mechanism *3* will once more rotate the valve, so as to cut off the steam being delivered into the upper half of the cylinder (Fig. 165, *d*).

THE FALLING PARTS OF HAMMERS

Falling parts of hammers include the piston rod, piston and ram.

Piston Rods. As regards design, piston rods can be classified into solid rods, i. e., those forged integral with their pistons, and rods with assembled pistons. Formerly the pistons and piston rods of steam hammers without guides were usually forged from one piece of metal. In steam hammers with guides, the pistons and piston rods are forged separately, and the piston is fitted onto the piston rod in a hot condition and then spread.

Fig. 166 shows a piston rod *1* with a removable piston *2*. The piston was hot fitted over the tapered section *3* of the piston rod. Head *4* of the piston rod after the piston has been fitted is spread to fill the tapered section of the piston.

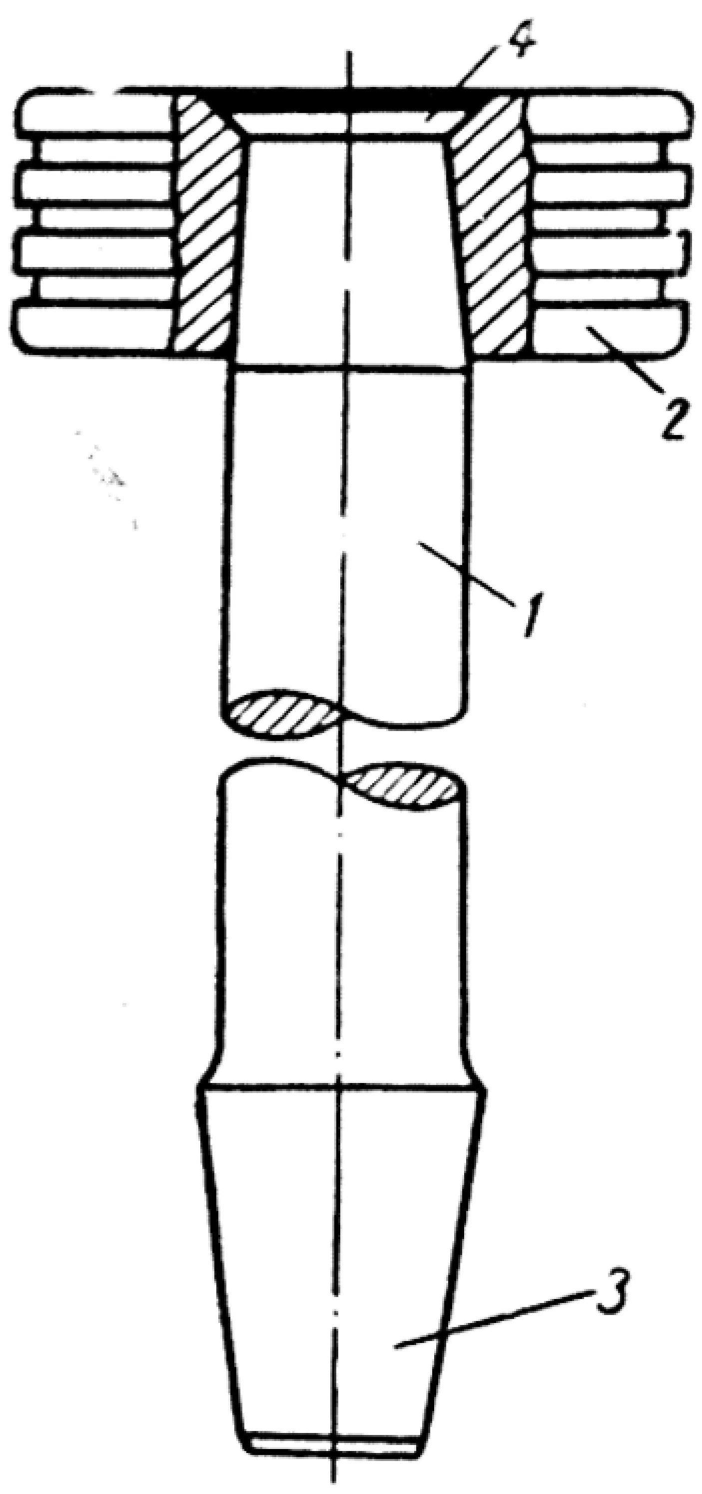


Fig. 166. Piston rod with assembled piston

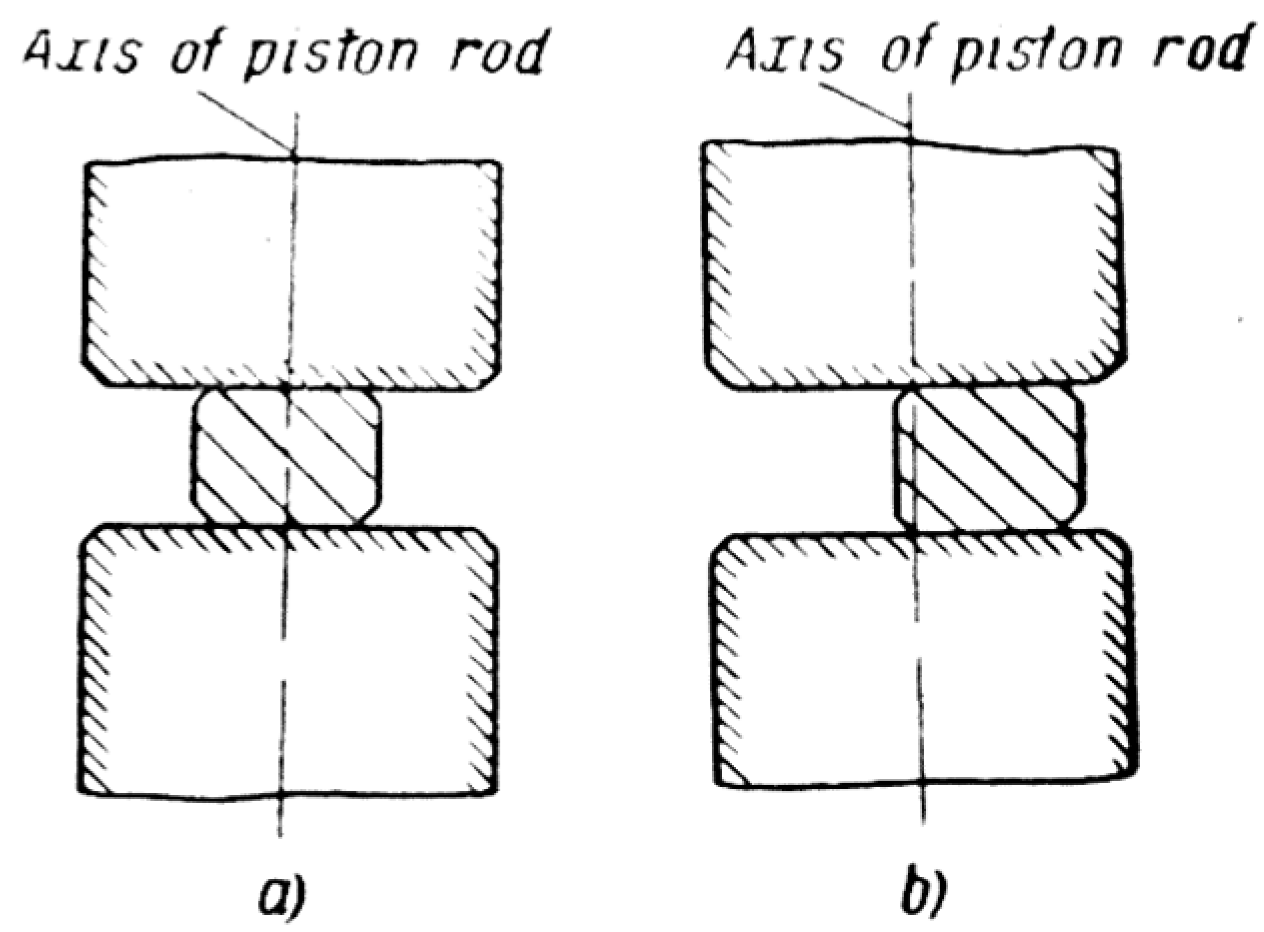


Fig. 167. Right (*a*) and wrong (*b*) position of forging

Piston rods are forged from carbon or alloy steels. Carbon steel piston rods are rarely used owing to their short life. Chromium-nickel or chromium-nickel-molybdenum steels are generally used for making piston rods, which are annealed after forging. After annealing, the piston rods are rough turned and then heat-treated (hardened and tempered). If the piston and the piston rod are forged integral, they are turned immediately after heat-treating. If, however, they are forged separately, the body of the piston is first machined on a lathe, fitted to the piston rod and spread; only then is the piston rod finished on the lathe together with the piston.

Piston rods have to be replaced more frequently than any other part of a hammer as they frequently break (every 4-12 months), when hammers are continuously subjected to heavy duty. The chief reasons for piston rod breakages are:

1. Faulty hammer design, loosening of fastenings (nuts, bolts, etc.) or wear of parts during the operation of the hammer. For instance, displacement of the axes of the piston rod and ram (the axes must always be in one line); misalignment of the axis of the cylinder relative to the guides, etc.

2. Poor mechanical properties of the metal from which the piston rod has been forged (presence of flakes, residual stresses, etc.).

3. Forging struck out of centre (Fig. 167) resulting in misalignment of ram and consequent breakage of piston rod.

4. Piston rod badly secured to ram.

5. Piston rod insufficiently heated before commencement of work, particularly in winter. Never start operating the hammer until the piston rod has been heated to a temperature of 150-200° C near the ram. Piston rods are usually heated by packing them with hot pieces of metal.

The piston rod is fitted to the cylinder through a *stuffing box* which is designed to prevent steam leaking from the cylinder. The stuffing box is fitted in a special recess in the cylinder, where it is secured with the aid of studs. The studs are fastened by nuts and lock nuts from the bottom, thus making it possible to tighten the stuffing box when necessary. As the packing wears out, it must be compressed by tightening the stuffing box or adding a few packing rings. Two types of gland packings are employed: hemp packing and graphitised asbestos packing rings. The latter are far better and serve far longer than hemp packing. The gland is packed by wrapping a piece of packing, equal in length to the circumference of the piston rod, around the latter taking care to prevent the ends of two adjacent rings from coinciding, as otherwise the packing will not be steam-proof and steam will leak between the ends of coils of the packing rings. When tightening up the stuffing box, all the nuts of the studs must be tightened up in turn and uniformly. In this way, the stuffing box will be forced upwards and firmly support the packing.

Pistons. Pistons are cylindrical in shape, with a diameter slightly less than that of the piston rod (1-2 mm less), and are fitted to the top tapered section of the piston rod (see Fig. 166).

In certain small hammers, piston rods forged integral with their pistons are used even nowadays. This design is more reliable, but more expensive, inasmuch as should the piston break, both piston and piston rod will have to be re-forged. For this reason, piston rods with replaceable pistons have nowadays displaced piston rods forged integral with their pistons.

In this case: 1) there is no need to forge the piston rod of the hammer from a billet of large dimensions; 2) the piston can be used for other rods (in practice, one piston can be fitted 5 times to piston

rods); 3) when the piston and the rod are separately forged, the heat-treating and machining processes are greatly simplified.

Pistons are forged from carbon steel containing from 0.45 to 0.55 per cent of carbon, and are normalised after forging. They are made with grooves in which the *piston rings* (Fig. 168) are inserted. Pistons are fitted with piston rings for the following reasons: 1) to fill the clearance between the piston and the cylinder of the hammer; this is necessary to prevent the leakage of steam from the bottom section of the cylinder into the upper section; 2) in order to give the piston a certain amount of "play" in its travel, as the piston rings act as springs during side blows; 3) to decrease the wear of the cylinder walls and the piston, thus preventing the occurrence of scratches on the cylinder walls and the piston and increasing their service.

Piston rings are made of softer steel than that used for the piston and cylinder. Steel containing 0.3-0.4 per cent of carbon and from 0.5 to 0.8 per cent of manganese is recommended for forging piston rings of hammers. Gray cast iron should never be used, as such rings are liable to break rapidly because of the shocks to which they are subjected. Piston rings wear out very quickly and therefore have to be frequently replaced.

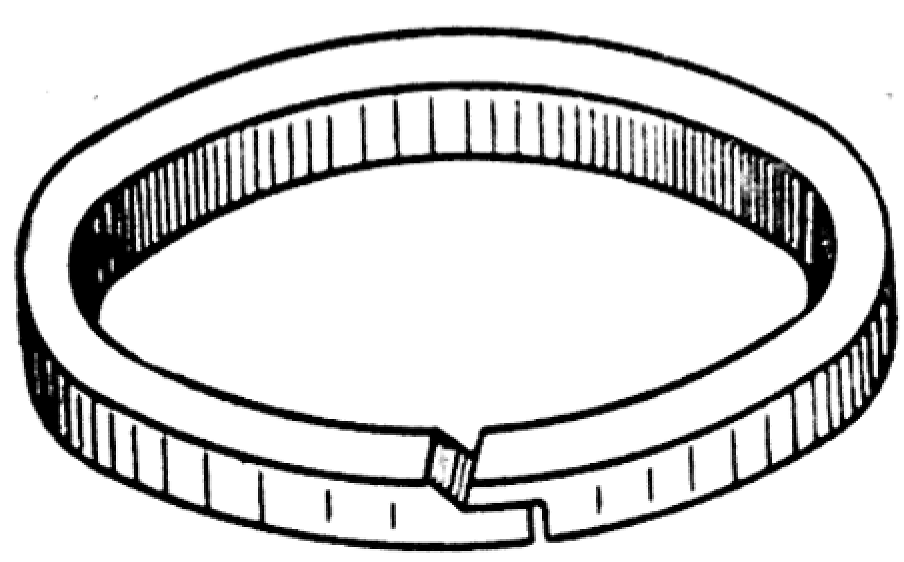


Fig. 168. Piston ring

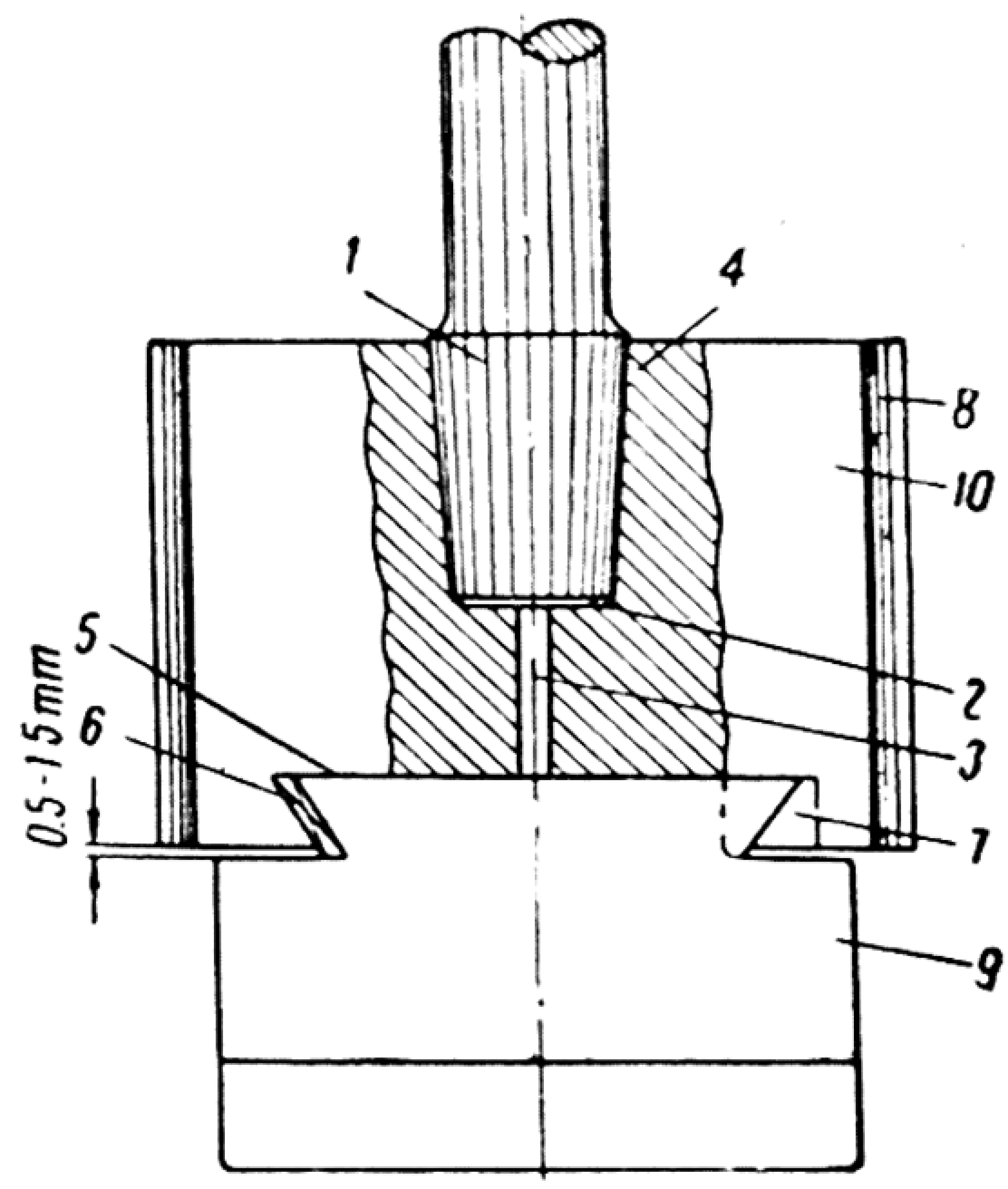


Fig. 169. Rigid attachment of ram to piston rod and attachment of ram head to ram

Rams. The bottom end of the piston rod ends in the ram, in which the upper die of the hammer is inserted by means of its dovetail. Sometimes, in small capacity hammers, the ram is forged integral with the piston rod. The advantage of such a construction is that it makes the entire falling system (piston, rod and hammer) far more rigid; however, this design is more expensive and complicated.

In modern forging hammers the rams and rods are made separate. For small capacity hammers the rams are forged, while for large capacity hammers they are made of cast steel. Rams can be made of carbon or of alloy steel. It should always be borne in mind that rams and dies made of high-alloy hard steel containing more than 0.5 per cent of carbon are liable to develop cracks; and that sometimes pieces of metal are liable to fly off at the fracture. This is very dangerous for the working personnel, and for this reason rams and top dies should be never made of steels containing over 0.5 per cent of carbon. They should likewise never be hardened.

There are many different ways of attaching the ram to the rod. This is a very important matter, as the rigidity of the piston rod, piston and cylinder, and the safe operation of the hammer, depend on how the ram is attached to the rod. The simplest method is that of rigidly attaching the ram and piston rod by a taper fit, as shown in Fig. 169.

By this method the tail end of the piston rod is forged to a greater diameter than the rest of the rod, and then turned down to a taper. A tapered recess is turned in ram *10* which has shoulders *8* to fit the guides. The tapered tail end of the piston rod *1* is forced into recess *2* of the ram. Before fitting the piston rod into the ram, the latter must be uniformly heated to a temperature of 400-450°C. This causes the tapered recess to expand and the tapered tail end of the piston rod will slide smoothly into the hole. On cooling, the ram will firmly hold the piston rod. Should the piston rod break, its end can be driven out of the recess through hole *3*; moreover, this operation is facilitated by the insertion of a copper gasket *4* between the piston rod and ram.

The bottom of the ram has a dovetailed recess *5* for the attachment of the top die *9* of the hammer. The die is secured to the ram with the aid of key *6* and lock pin *7*. To avoid breakage of the die and ram, the central section of the die should press firmly against the dovetail recess in the ram, with a clearance of 0.5-1.5 mm between the ends of the ram and the dovetail wings. Lock pin *7* must be constantly checked and, when replacing dies, must be withdrawn and carefully inspected as otherwise it will be liable to stick so firmly in its recess, that its removal will be impossible. Prolonged operation may result in dents in the die where it contacts the ram. These dents must be removed from time to time by machining on a planing machine in order to ensure the correct installation of the die. The length of key *6* must be such that, when driven into its keyway, it will project only slightly. A long projecting part of the key may cause severe accidents to the operators.

The key is driven into the keyway with a sledge-hammer, and must be tightened up from time to time, as it is liable to work loose

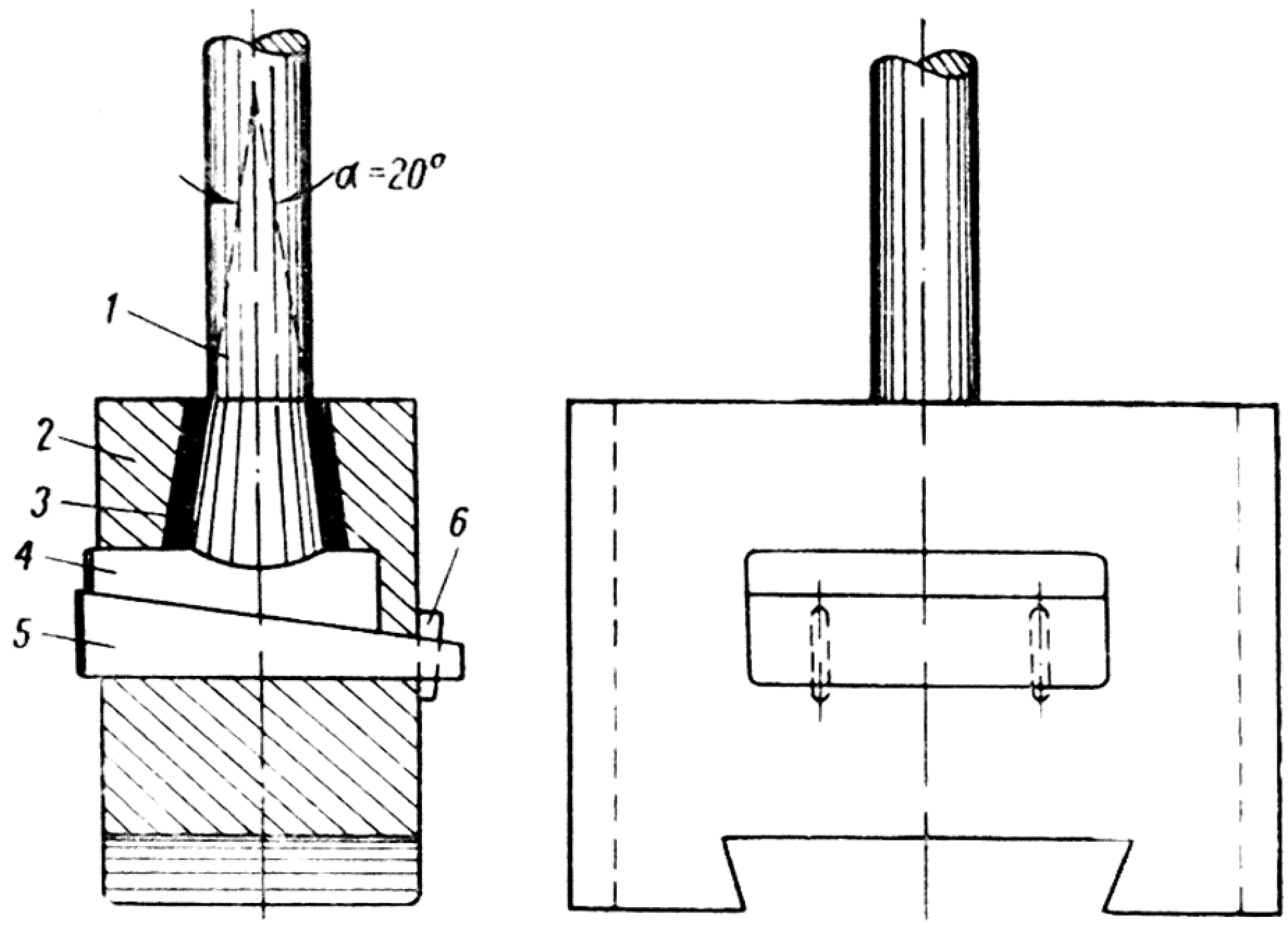


Fig. 170. Dismountable assembly of piston rod with ram of hammer

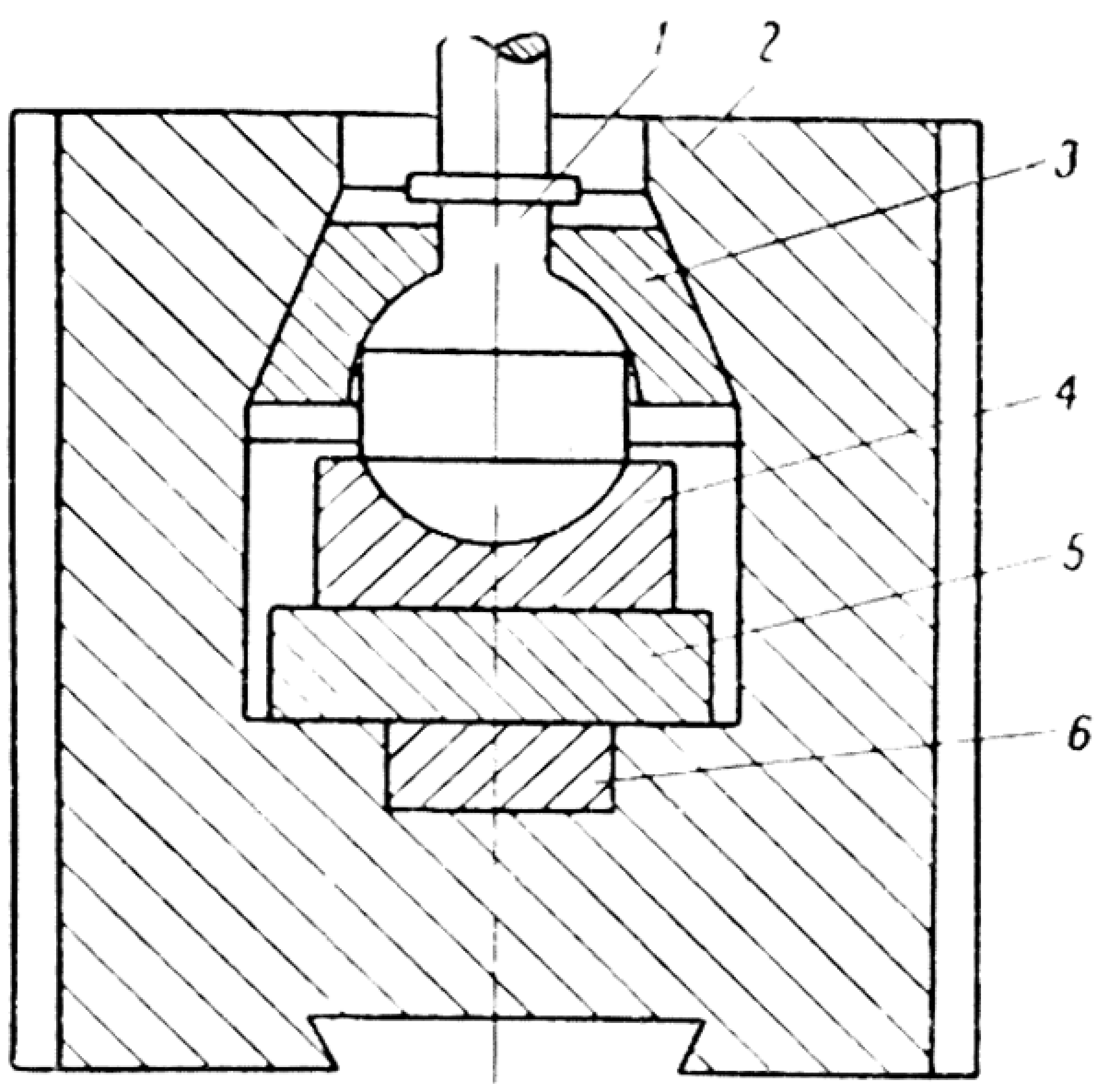


Fig. 171. Dismountable assembly of piston rod with ram of hammer (Uralmash Works)

during the operation of the hammer. Gaskets should not be inserted between the ram head and the die block, as they may lead to breakage of both ram and die. The blacksmith must always see that the maintenance staff have the die planed to fit the ram.

Removing the broken end of a piston rod from the ram is a very difficult job, but this difficulty can be avoided if the attachment of the piston rod to the ram is carried out as shown in Fig. 170 (assembly attachment). Here, piston rod *1* is made with a reverse tapered tail, which is inserted into ram *2*. Piston rod *1* and liner *3* are secured in place by bushing *4* which is fastened by wedge *5*; the latter is secured by lock pin *6*.

An assembly attachment of a different design, illustrated in Fig. 171, is used at the Uralmash Works and other Soviet plants. Here, the spherical-headed tail of piston rod *1* is inserted into ram *2*. A split tapered cup is placed between the piston rod and the ram. The hollow of the cup is made to fit the upper part of the spherical head of the piston rod. This cup supports the piston rod during its upstroke. The bottom of the spherical head thrusts against recessed thrust block *4* which is held against the piston rod by key *5*, beneath which is installed thrust block *6*.

This design of fastening the piston rod and ram permits the ram to change its position relative to the piston rod and to protect it from breaking when striking blows out of centre.

PROTECTIVE DEVICES

Careless control of hammers and breakages of the piston rod may result in the piston striking against the cylinder cap with considerable force and causing its breakage. To prevent any possibility of breaking the cylinder cap and the consequent breakdown of the hammer the cylinders are equipped with special protective devices located at the top of the cylinder: the steam or cushion protective devices and the stop spring protective devices.

The *steam protector* (Fig. 172) consists of cushion cylinder *1* bolted to the top of cylinder *8* (instead of its upper cap), cap *2* and plunger *3*. Plunger *3* is fitted with two or three rings. Steam or air is delivered along pipe *4*, fitted with a stuffing box *5*. Cylinder *1* has three horizontal ports *6* the dimensions of which depend on the hammer capacity.

This protective device operates as follows. When piston *7* strikes against plunger *3* the latter rises and closes port *6* thereby cutting off the outlet of the steam; the steam remaining inside cylinder *1* is compressed and thus prevents any further movement of the plunger and, consequently, prevents the piston rod from rising further.

The *spring stop* (Fig. 173) consists of: pin *1* which passes through top cap *1* of cylinder *3* of the hammer. When piston *4* strikes pin *1*, the latter rises and spring *5* hitting against cross bar *6* is compressed, thereby absorbing the blow. Spring stop-type protectors have the following disadvantages compared to steam (or air) protectors:

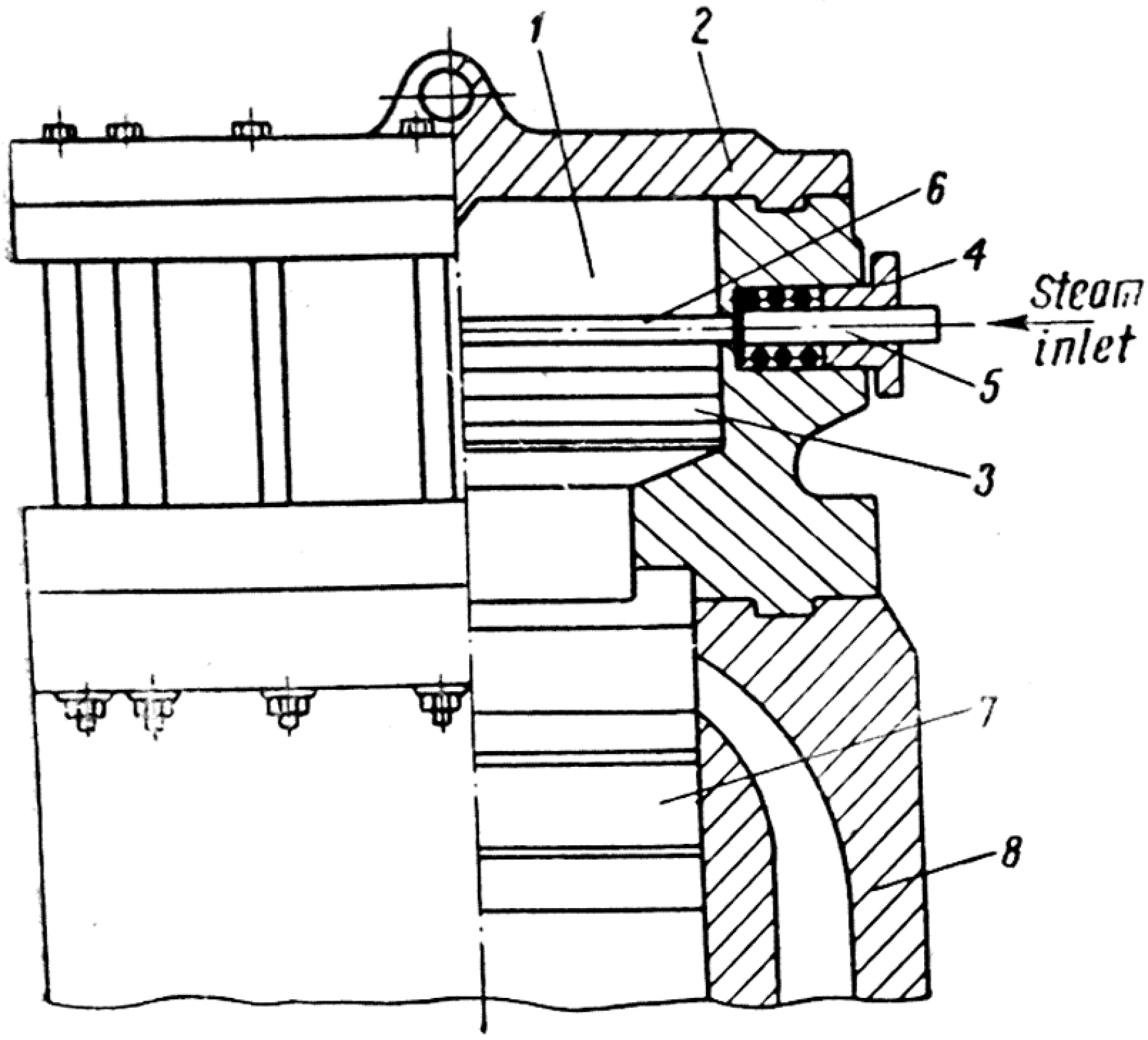


Fig. 172. Steam protector

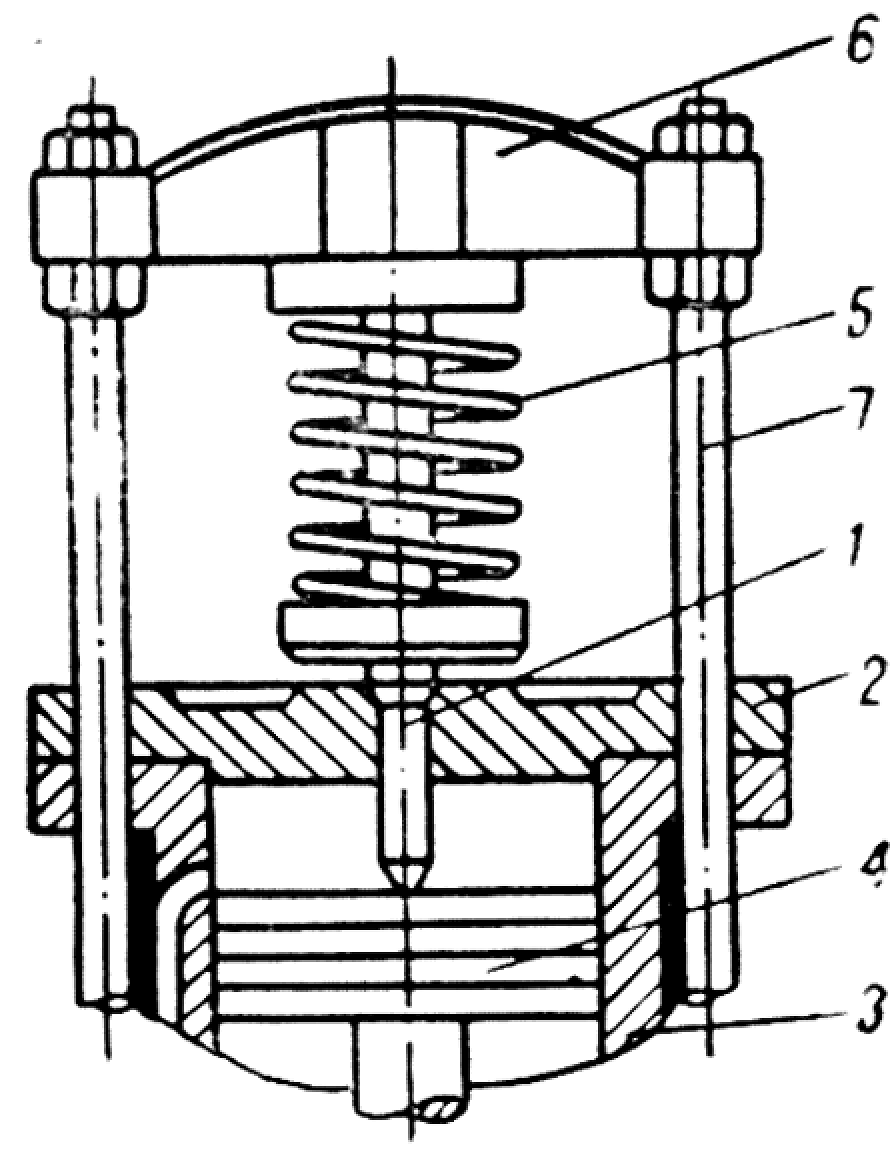


Fig. 173. Stop spring protector

1) the difficulty of regulating the plunger so as to avoid breakages of the spring; 2) should any of the tie bolts *7* break, the broken parts of the bolt may cause injuries to persons standing near the hammer.

STEAM HAMMER LUBRICATION

Proper lubrication is one of the most important conditions ensuring the normal operation of any forging hammer. However well the different parts of a steam hammer may be fitted to each other, if they are not lubricated, or improperly lubricated, the hammer will always work inefficiently. In some cases, improper or insufficient lubrication may lead to a breakdown of the hammer or even its breakage. The better the hammer mechanisms are lubricated, the less energy will be spent on overcoming friction between the various reciprocating parts. The better the hammer is lubricated the less will its parts wear and the less repairs will it require, thereby considerably reducing idle time. Consequently, hammer operators must carefully look after the reciprocating parts of their hammers and see that they are always properly lubricated.

The rotary valve cylinder and the throttle must be lubricated with *cylinder oil* which is fed into the steam inlet pipe together with the steam. The method of lubrication is shown in Fig. 174. Cylinder oil is poured into lubricator *1*, which is a mechanism for forcing the oil into pipe *2*. It is mounted on the frame or on the anvil block of the hammer, to which it is secured with the aid of bracket *3* and bolts. Oil line *2* comprises a coiled copper tube of 8-10 mm inside diameter. The upper end of this oil pipe is inserted inside a special valve *4*.

The lubricator is operated by a system of levers (Fig. 174, *a*).

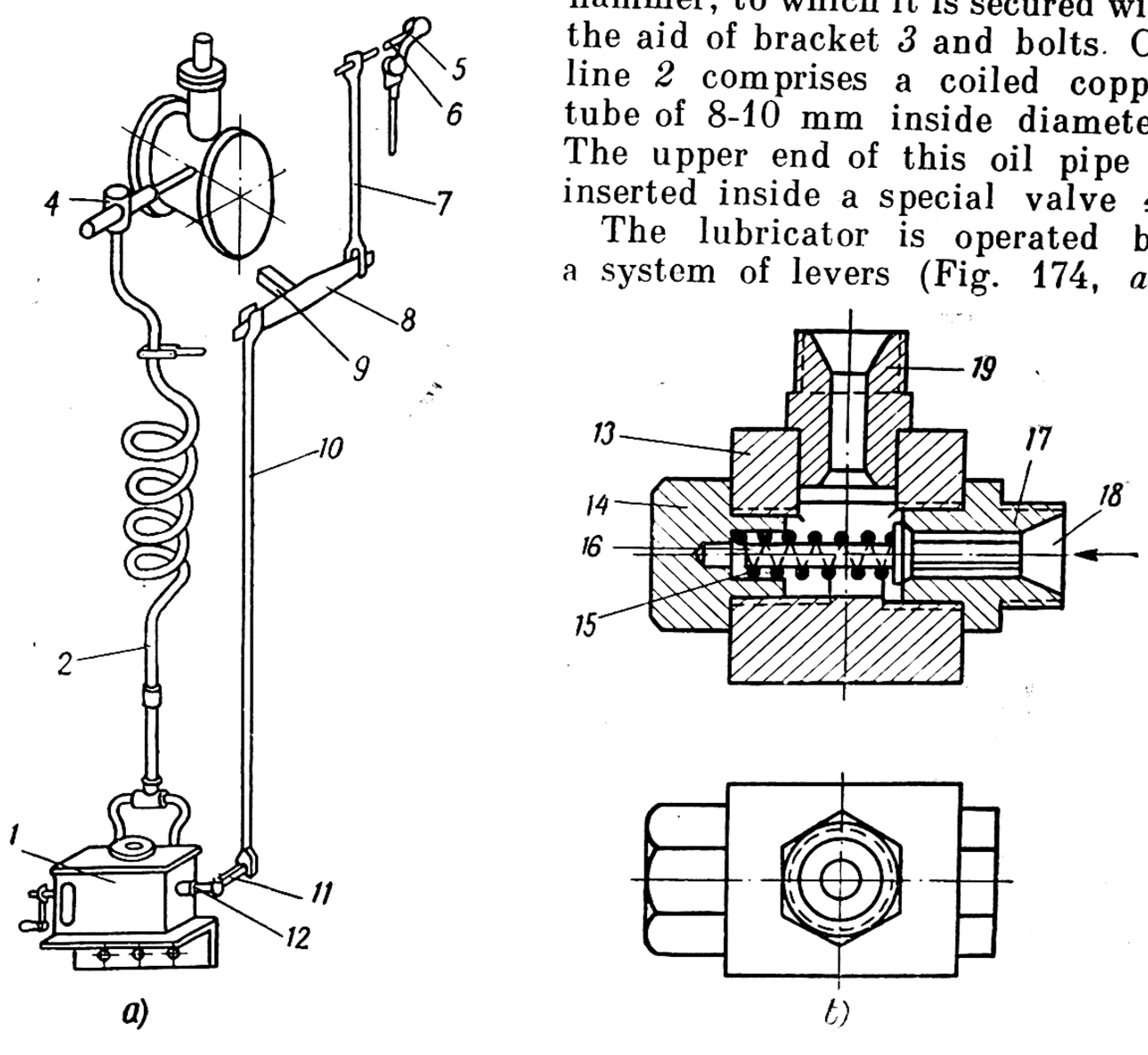


Fig. 174. Slide valve and throttle lubricating diagram

Link *6*, connected to tie rod *7* through a universal joint, is attached to valve rocker *5*. The tie rod is also connected through a universal joint to rocker *8* which is freely mounted on bracket *9*, which is in turn secured to the anchor plate of the hammer. The other end of rocker *8* is connected to rod *10*, the bottom end of which is attached to lubricator lever *11*. Thus, at every upward stroke of the slide valve, lubricator lever *11* will slightly turn lubricator shaft *12*, thereby forcing a portion of oil into oil pipe line *2*. As the rotary valve rod is constantly travelling up and down during the entire operation of the steam hammer, the lubricator will be in constant motion, ensur-

ing a continuous delivery of oil. From the oil line the oil flows into the valve *4* illustrated in Fig. 174, *b*.

The body of this valve has two holes. The left-hand hole is plugged with a special bolt *14* with a recess in which are inserted spring *15* and valve *16*. The flange of valve *16* thrusts against nut *17* which is screwed into the right-hand hole of the valve body. The end of the oil pipe is inserted into hole *18* of nut *17* through a special union. Oil is delivered under pressure along the oil line from the lubricator. This pressure compresses valve spring *15*. From here, the oil flows through the third top hole in nut *19* into the steam inlet pipe of the hammer.

The oil, on entering the steam line, is atomised by the steam and mixes with it uniformly. Owing to the fact that the temperature of the cylinder walls of the hammer is lower than that of the steam, the steam condenses on the walls, and the oil mixed with the steam creates a thin lubricating film. To ensure better atomisation of the oil, the oil pipe must be inserted exactly in the centre of the steam pipe.

The guides are lubricated with grade T nigger oil, which possesses a high degree of viscosity. They must be greased by hand, with a long-handled brush so as to protect the hands of the hammer operator lubricating the guides from being caught by the moving parts. When greasing guides, it is always necessary to make sure that they are evenly greased along their entire length, and that no foreign matter, like scale or chips of metal, fall on them. Otherwise the guides will be scratched.

To ensure the easy operation of the hammer, the universal joints of the control rods and levers should be regularly lubricated. Universal joints which rotate in roller bearings must be greased with solidol. Bushed joints must be lubricated with *machine oil*.

SELECTING AND CALCULATING THE CAPACITY OF A HAMMER

In hammer forging, the necessary reduction and, consequently, good-quality forgings, are difficult to attain on hammers of insufficient capacity. In addition, the forging time will be longer, more heatings will be required, the fuel consumption and loss of metal due to scale will be increased, as also the cost of the forging itself. If, on the other hand, a forging is made on a hammer of more than the required capacity, the forging cost will be increased as a result of increased overhead expenses. For this reason, the question of the proper selection of hammer capacity for making a given forging acquires great importance.

The necessary *weight of the falling parts* of a hammer depends on: 1) the cross-sectional area of the forging; 2) the operations entailed

in making the forging (drawing, upsetting, etc.); 3) the material of which the forging is to be made, and on a number of other conditions. The question as to which hammer to employ for making a definite forging is usually decided by the shop administration: the blacksmith is given a process chart which indicates the method of making the given forging and the equipment on which it is to be made. But every blacksmith should know that the forging which he is to make must be made on a hammer of the proper capacity. This is necessary to enable him to increase his productivity and to try to lower the cost of his forgings. As a rule, the required capacity of the hammer is selected by formulas, charts and tables which have been drawn up on the basis of experience. Table 7 gives data for determining the capacity of a hammer required for the production of forgings depending on their weight and cross-section.

Table 7

Chart for Selecting Hammer Capacities

Weight of falling parts, kg	Weight of forgings, kg			Maximum cross-section of stock, mm (diameter or side of square)
	Shaped forgings		Smooth shafts	
	Average weight	Maximum weight	Maximum weight	
100	0.5	2	10	50
150	1.5	4	15	60
200	2.0	6	25	70
300	3.0	10	45	85
400	6.0	18	60	100
500	8.0	25	100	115
750	12.0	40	140	135
1,000	20.0	70	250	160
2,000	60.0	180	500	225
3,000	100.0	320	750	275
5,000	200.0	700	1,500	350

Charts for selecting the weight of the falling parts of hammers have been drawn up on the basis of data supplied by G. Reznichenko, E. Duletov and I. Grigoryev. Figs 175 and 176 give diagrams for: 1) selecting the weight of falling parts of a hammer for rolling rings, depending on their inside diameter and height; and 2) determining the weight of the falling parts of a hammer for making gear-type forgings by the upsetting method.

Example of Employing the Diagrams. It is required to determine the weight of the falling parts of a hammer for making a ring by rolling, if d (inside diameter) = 800 mm and h (height) = 185 mm.

Solution: A point corresponding to 800 mm is marked off on the vertical scale of the diagram (Fig. 176) and a point corresponding to

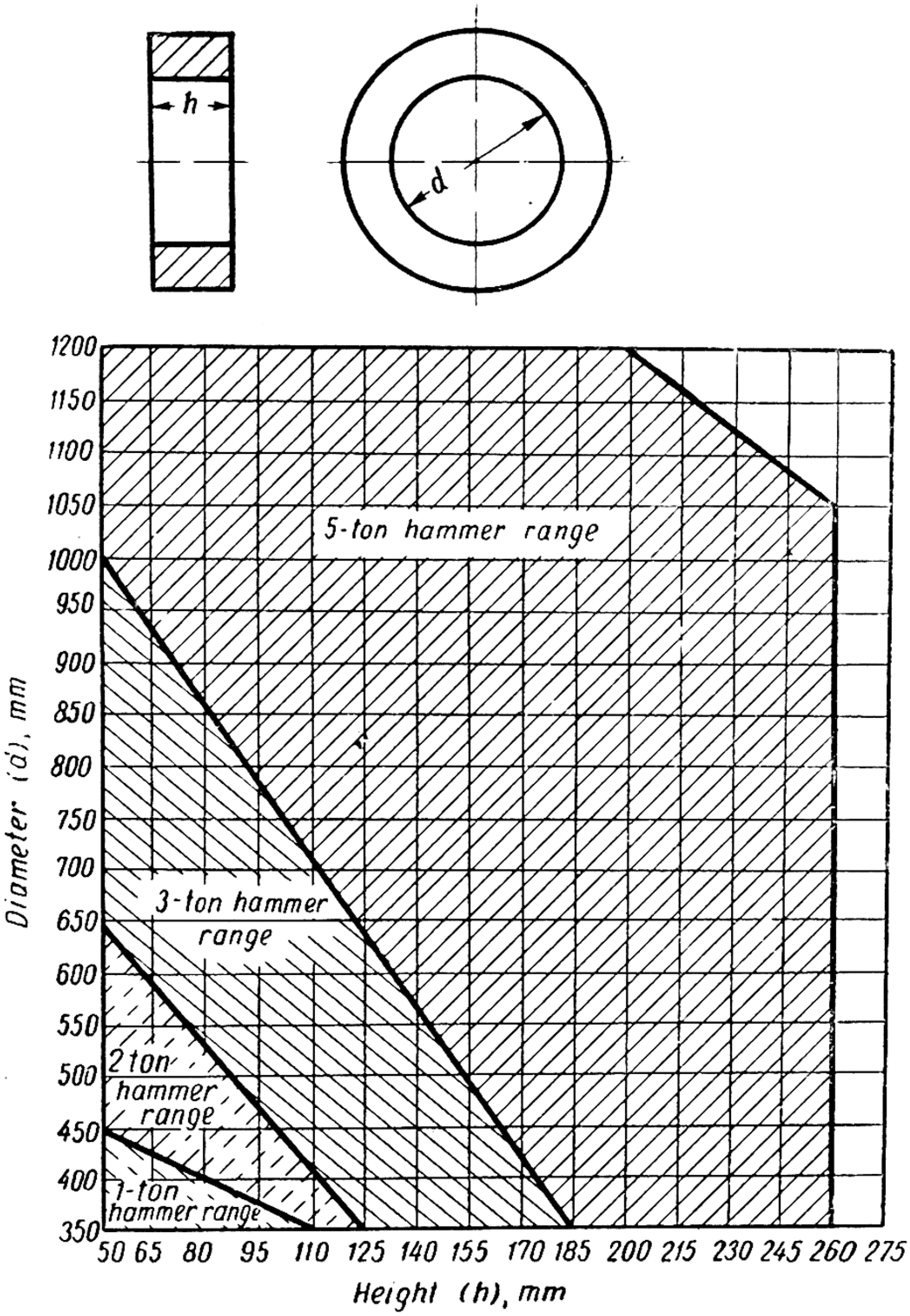


Fig. 175. Chart for selecting weight of falling parts of a hammer for rolling ring-type forgings

185 mm—the height of the forging—on the horizontal scale. From the point corresponding to 800 on the vertical scale, a horizontal line is drawn, and a vertical line from the point corresponding to 185 mm

on the horizontal scale. The point of intersection of these two straight lines will fall within the range of hammers with falling parts weighing 5 tons. Consequently, a hammer of 5-ton capacity will be required for forging the ring.

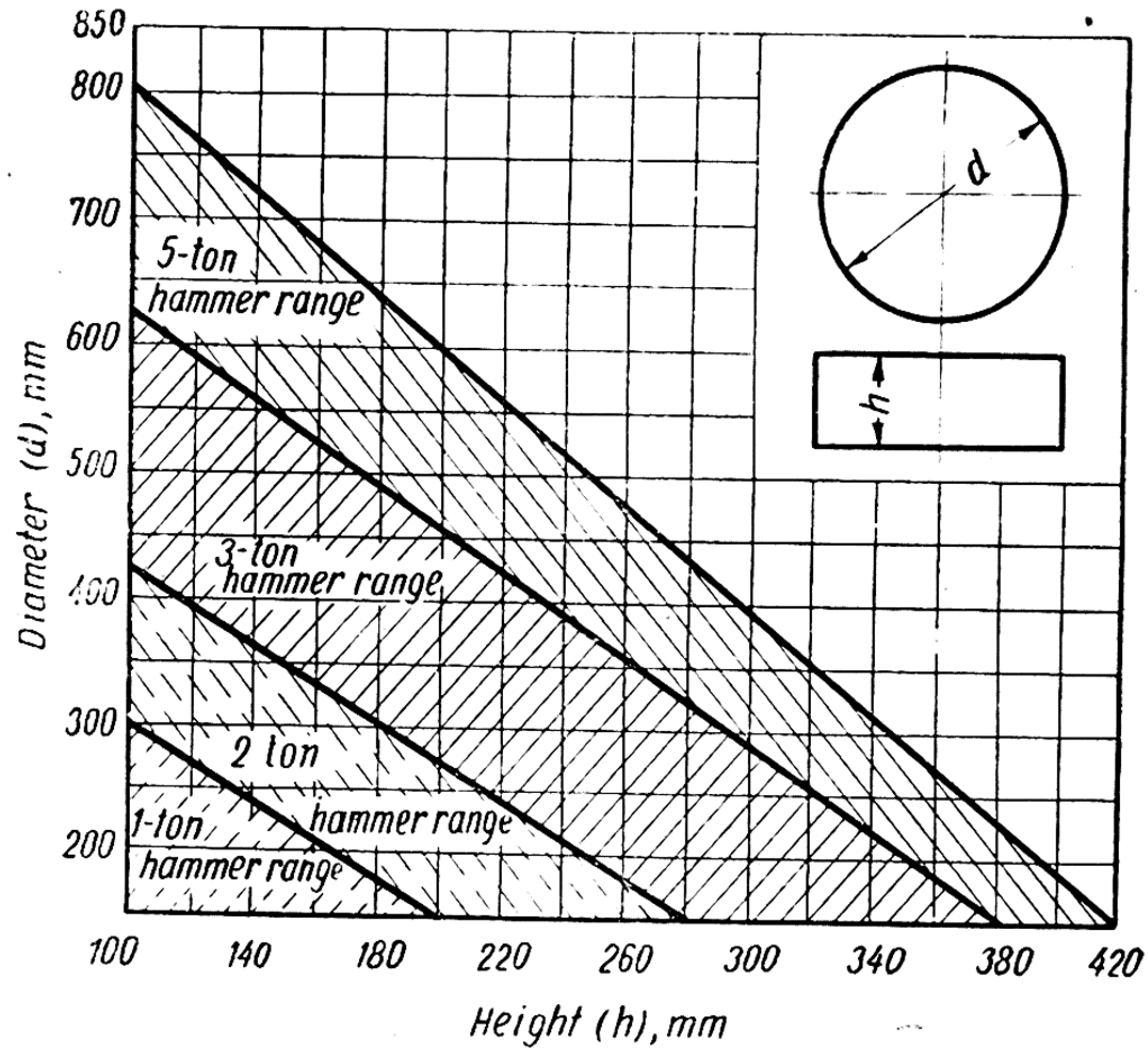


Fig. 176. Chart for selecting weight of falling parts of a hammer for upsetting gear-type forgings

MAINTENANCE OF STEAM-AND-AIR HAMMERS

Before commencing work, always:

1) Inspect the hammer for any damage and defects; see that it is properly lubricated; that the dies are reliably secured; that the top and bottom die blocks are in perfect alignment; that the piston rod and the upper die block are properly heated;

2) Check the die-blowing mechanism;

3) Prepare all tools for work;

4) Remove all tools, fixtures and other objects not directly needed for the work in hand;

5) Open the steam-and-air line exhaust valves fully, then slightly open the air-and-steam line inlet valves and blow out the steam and air system, after which fully close the steam inlet valve;

6) Remove all water which may have accumulated in the cylinder after prolonged shutting-down of the hammer (for repairs, rest days, holidays, etc.).

During operation, it is necessary:

1) To see that the keys securing the die blocks to the ram and anvil block are firmly driven into place; see that the top and bottom dies are in perfect alignment;

2) To avoid idle blows of the top die against the bottom die; heavy idle blows may break the piston rod;

3) Not to forge metal which has cooled below the permissible temperature;

4) To see that the tongs are never caught between the dies; always hold the handle of the tongs sideways, and never directly in front of you;

5) Never allow the dies to be examined or cleaned while the hammer is in operation; before doing so, always stop the hammer and lower the ram on a special fixture;

6) To give your orders to the hammer operator loudly and clearly; to indicate the required force of the blow by the following commands: "Strike lightly", "Strike more heavily"; and indicate the number of blows by the commands: "Strike once", "Strike twice", "Strike", "Stop"; only the blacksmith may give orders to the hammer operator; his helpers may not give any orders to the hammer operator;

7) When the job in hand is finished, stop the hammer by giving the order "Stop"; and, only after the hammer has been stopped, remove the forging from the bottom die;

8) Always warn the hammer operator before placing any tool on the forging or changing its position.

After the completion of the day's shift:

1) Stop the hammer and lower the ram smoothly;

2) Close the valves on the steam inlet and outlet lines;

3) Remove all tools, fixtures, forgings and waste metal to their proper place;

4) Check the chief parts of the hammer and report all defects and troubles to the maintenance man on duty or to the foreman;

5) Put your working place in order and wipe the hammer clean.

DROP HAMMERS

Drop hammers include all power driven hammers in which the ram, after being raised to a definite height, falls freely under its own weight. The force of the blows of these hammers will be the greater, the greater the weight of the ram and the height of its fall. Usually, drop hammers are employed for stamping (die-forging) light and medium weight forgings.

The following types of drop hammers are employed in modern forge shops: 1) belt drop hammers, in which the ram is suspended from a belt; 2) rope drop hammers, with the ram suspended from a rope; and 3) board drop hammers.

Belt Drop Hammers. Fig. 177 shows the arrangement of a belt drop hammer. Ram *1* is suspended from belt *2*, which is passed over rotating pulley *3* mounted on shaft *4* and rotated by sheave *5*. Flywheel *6* is mounted on the opposite end of shaft *4* which runs in bearings *7*.

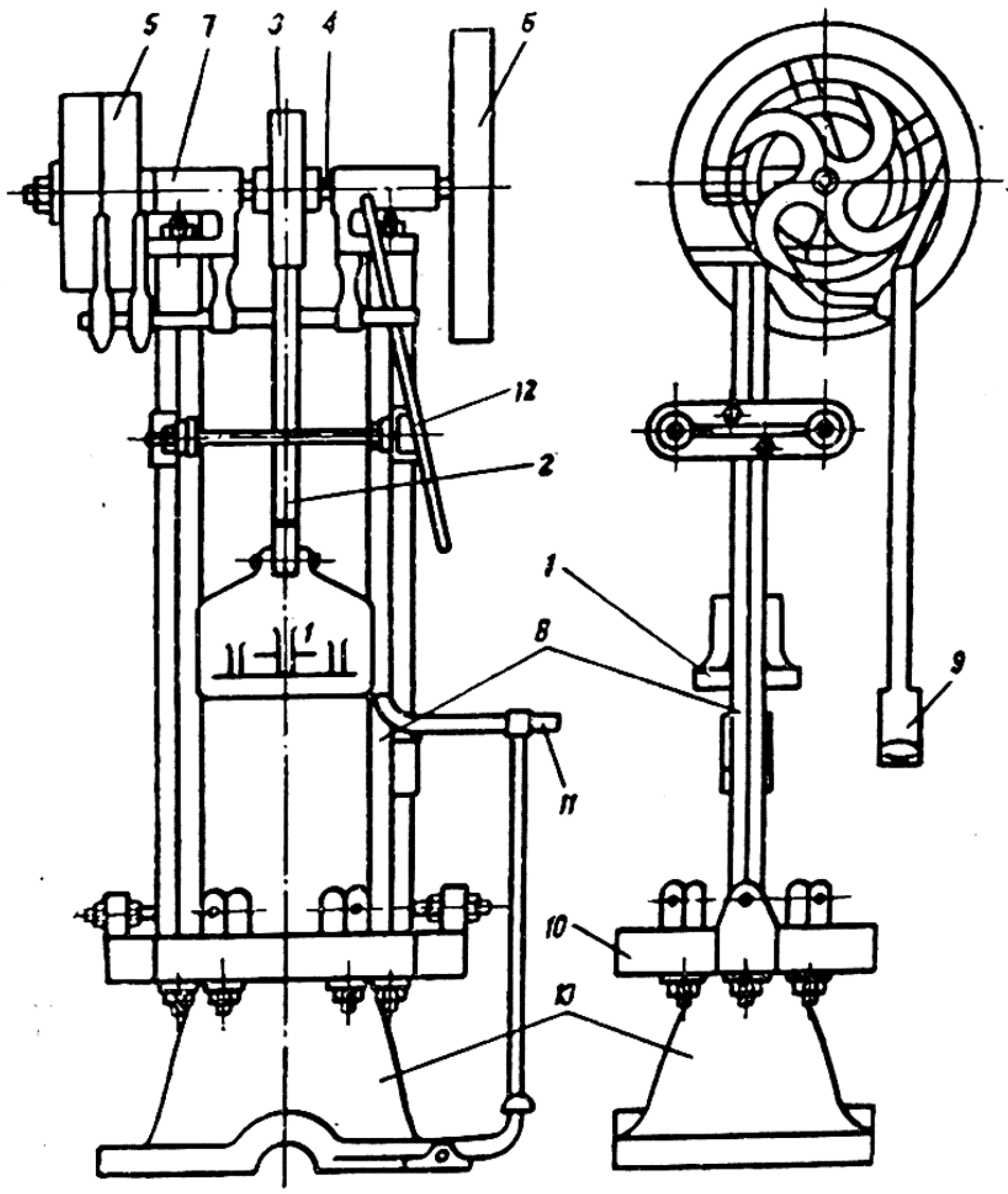


Fig. 177. Belt drop hammer

The ram travels in guides *8*. If we pull the belt by means of handle *9*, it will be pressed against pulley *3*. As a result of the friction arising between the belt and the pulley the latter will carry the belt with it, raising the ram. If we then release the belt, the ram will fall under its own weight onto the forging on the anvil or bottom die. The anvil or bottom die rests on plate *10* of anvil block *13*. Lever *11* serves for holding the ram at any desired height; lever *12* serves for starting pulley *3*. The disadvantage of these hammers consists in the rapid wear of the belts which are in constant contact with rotating pulley *3*.

The mechanism of belt drop hammers is operated by 5-15-hp electric motors. Generally, these hammers are made with rams from 100 to 150 kg in weight.

Board Drop Hammers. The operation of a board drop hammer will be clear from Fig. 178. Board *1* (Fig. 178, *a*) to the lower end of which is attached ram *2* is installed between two rotating rolls *3*. On pressing the rolls against the board, the friction between them and the board will raise the latter, and with it, the ram. Fig. 178 shows

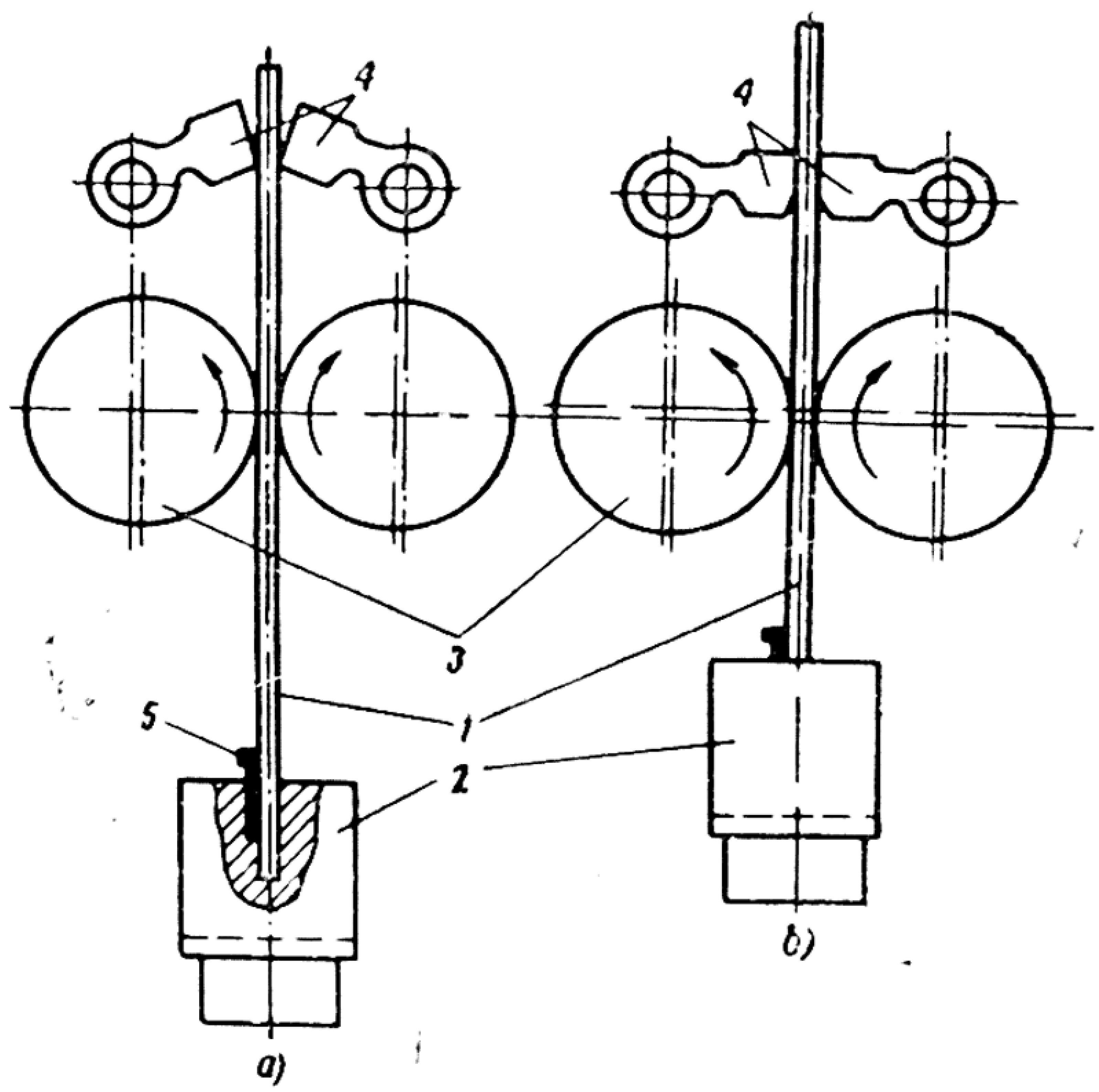


Fig. 178. Scheme of board drop hammer

the ram held in its top position with the aid of brake shoes *4*. On raising the brake shoes *4* as shown in Fig. 178, *a*, the board, and with it the ram, will drop and strike the forging.

The ram is made of forged or cast steel. During its travel, the sides of the ram, which are grooved, slide in guides of the frame posts. The top die is secured to the lower part of the ram with the aid of keys.

The board is attached to the head of the ram with the aid of key *5* and pressure bolts. Boards are usually made of high-grade hard wood, beech, for instance.

In modern board drop hammers, each roll is rotated by a separate electric motor. They are switched in automatically by a lever operated by the ram during its up-stroke. The position of this lever can be adjusted to regulate the height to which the ram is raised. After the rolls have been disconnected, the board will be held in its raised position by brake shoes *4* until they are raised by depressing the treadle.

Drop hammers are employed for die stamping miscellaneous work of light and medium weight. The disadvantages of these hammers are: 1) the boards are liable to frequent breakages; 2) the difficulty of controlling the force of the blow during operation.

Maintenance of Drop Hammers. Before commencing work on a drop board hammer, the blacksmith must check all bolt fastenings, the boards, belts and die blocks; see that the ram is not cracked and that the die is securely fastened to the ram, etc.; check the fastening of the reductor and electric motors on the top of the hammer. Before inspecting the top part of the hammer, current must be switched off. All unneeded objects, such as wrenches, tools and small pieces of work must be removed from the top of the hammer.

After the hammer has been checked and the working place has been prepared (tools, fixtures and stock), the electric motors can be switched on. The hammer must be started gradually, and the electric motor allowed to run idle for some time. After making sure that the electric motors are running properly and that the hammer is in good condition, a few blows may be made on a board placed on the bottom die. In doing so, the blacksmith must take special care to see that the ram does not fall when held suspended, i. e., that the brake shoes work properly. If, for any reason, the ram starts slipping when it should remain suspended (for instance, because the board has become worn, or is not of the proper thickness), work on the hammer should not be commenced, as the ram may fall unexpectedly and cause severe injuries to personnel or result in a breakdown.

During the operation of drop hammers, the same rules as for the operation of mechanical and steam hammers must be observed.

HAMMER OPERATION SAFETY RULES

The blacksmith must always hold the forging horizontally on the anvil, or bottom die of the hammer. This is particularly important with old hammers, the anvil blocks of which usually sink into the soil as a result of the sinking of the foundation. In practice, the anvils (bottom dies) of such hammers are frequently much lower than is required to ensure the normal position of the blacksmith's body during his work. When a blacksmith forges a long piece of stock, he frequently has to look along the length of the forging to see that it is perfectly straight; to do this, he is obliged to bend to the level of the anvil (or of the bottom die), or else raise the end of the forging. As it is very inconvenient and fatiguing to work on an anvil or bottom die located at a low level, it is natural for the blacksmith to prefer raising the forging. Should the ram strike the forging when it is raised for inspection, the blow will unavoidably tear the forging or tongs out of the blacksmith's hands. For this reason the normal height of

the face of the anvil or of the bottom die above floor level should be from 650 to 750 mm.

The top and bottom dies must be of the same width. A top die wider than the bottom die will be dangerous, because the tongs holding the forging can in this case be forced down and torn out of the blacksmith's hands by the overlapping of the top die. Therefore, as a rule, the top and bottom dies must be of equal width, and their edges should coincide.

The top and bottom dies must always make perfect contact with each other and be in perfect alignment. Improper contact of the dies, or uneven settling of the anvil block may lead to clearances between them at one side. This will, during forging, result in uneven deformation of the stock, and lead to crooked forgings. Moreover, when the dies are so positioned, the tongs will always be subject to considerable strains, and sometimes the blacksmith will be unable to retain his hold on them, and they may fly out and injure nearby personnel. The same may happen if the top and bottom dies are out of centre, or misaligned, as a result of faulty keying of the top die in the piston rod, or as a result of the piston rod itself being out of centre in the gland.

The forging must always be held in the centre of the anvil (or bottom die). Burnt metal, or metal which has cooled below the permissible temperature must never be forged. As a rule, the blacksmith and the hammer operator must see to this; and they will act properly if they refuse to forge cold metal.

When cutting hot metal, the last blows must be lighter, and great care must be taken to place the cutting tools correctly on the work. Never cut cold metal without special fixtures. If the forging is being executed with the aid of a crane, i. e., if it is suspended from chains, care must be taken to see that the impact of the hammer is not transmitted to the chain—the chain should always be slackened out in time.

Hand tools should never be held at right angles to the body; for instance, the handle of a hammer should always be held at the side.

All scale falling off the forging must be brushed away from the anvil or bottom die. This is extremely necessary, both for safety's sake, and to ensure a clean surface of the forging. Scale should never be removed with bare hands, or even with gloved hands, as the hand or glove may be crushed between the hammer dies. Every hammer must be equipped with a long hose with a nipple, connected to an air or steam line, for blowing the scale away. In the absence of a hose, the scale can be removed with a brush or broom, which must always be placed near every hammer. The stuffing boxes must always be properly drawn up, to prevent hot condensed water from leaking when

the hammer strikes, and causing burns. If the anvil or bottom die is wet, because of leakage from the stuffing box, the scale which falls on the anvil or die during work will fly off in all directions with great force, which can be dangerous to people standing near.

Before commencing work on a steam hammer, the condensed water should always be removed from the cylinder. The valve chest should be warmed by letting in the steam gradually. Then the cylinder is run in with several idle strokes of the piston rod.

The top die and the piston rod must always be heated before commencing work. This can be done by placing a hot bar on the die and wrapping tow impregnated with masout round the piston, and setting fire to it. It is particularly important to heat the piston rod and die in winter. As a rule, work should not be started in winter if the temperature of the die and rod is less than 50-100°C.

All protruding and moving parts of the hammer must be protected in order to avoid accidents. If the hammer is operated with the aid of a treadle the latter must be protected so as to prevent all possibility of its being accidentally depressed.

The hammer operator strikes the work at the blacksmith's orders but if he notices that the blacksmith has placed his tool on the work wrongly, or is about to use a dangerous method in his work, he must refrain from striking, and is bound to warn the blacksmith of his mistake. The hammer operator's duties also include keeping the stuffing boxes in good condition, drawing them up whenever needed and replacing old and worn-out packing.

The keys of the dies must always be tightened up in good time. As a rule, idle blows of the top die against the bottom die should never be allowed. When stopping the hammer, the ram must be gently lowered to its extreme lower position and the hammer motors switched off.

It should never be attempted to make any repairs or adjustments to the hammer during its operation. Also, all the safety rules should be strictly observed when repairing hammers and operating auxiliary equipment.

Replacing Dies. The dies are delivered to the hammers by overhead travelling cranes. Dies are made with handling holes, and, when being handled, rods are inserted into the holes of the die, the crane chains slung over the rods, and the die is then delivered to the hammer. But as a rule the hammer prevents the chain from being brought exactly into the position for installing the die. The workers have to swing the die until it is exactly over its place of installation; at this moment, the chain must be rapidly lowered, and the die will fall into its required position. But the first attempt is not always successful and the operation must be repeated, often several times, before the die falls in place.

This method of installing dies is by no means safe; the chain may fly off the rods and injure nearby workers; moreover, fingers are frequently crushed during the lowering of the die into position. Therefore, special fixtures have to be used for installing dies; Fig. 179 shows one of these fixtures which ensures safer working conditions.

This fixture consists of rod *1*, welded into the groove of counterweight *2*. Two hooks *4* are mounted on this rod, and handle *3* is welded to the counterweight. From the end opposite to the counterweight are suspended two endless chains, with their slinging links *5* slung

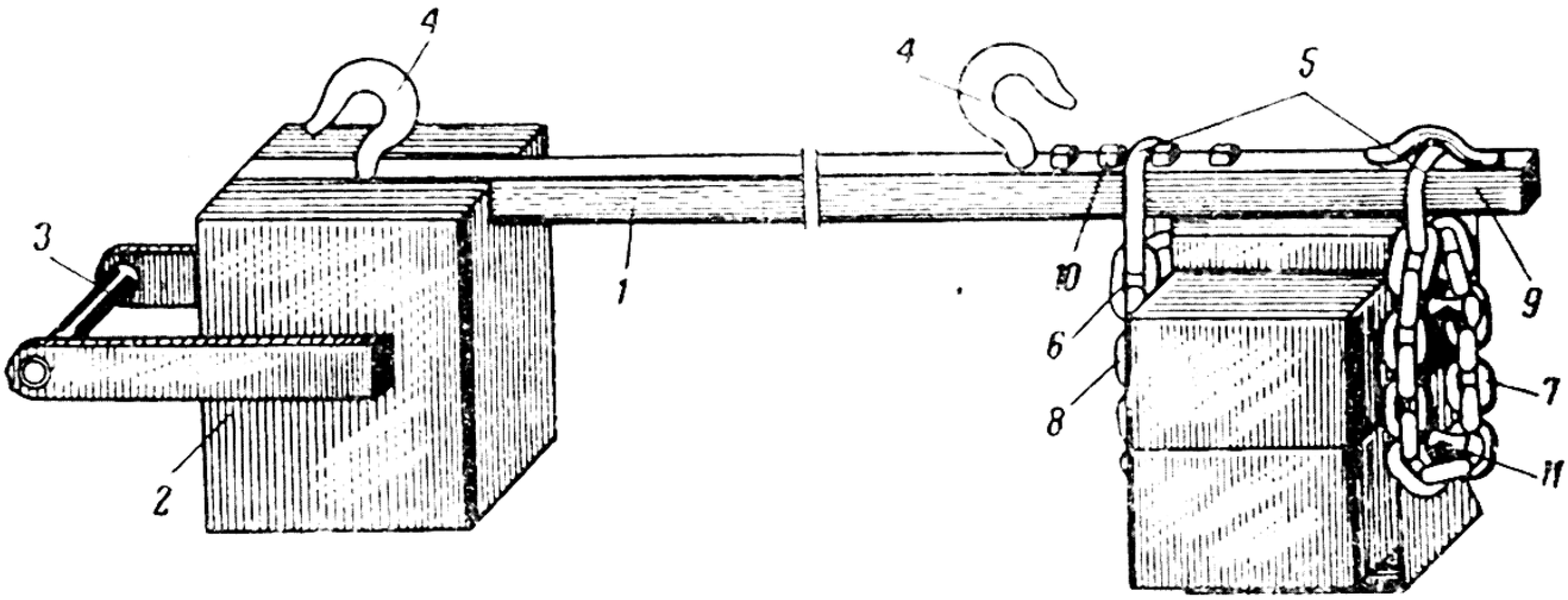


Fig. 179. Fixture for installing dies and stamps

through connecting ring *6*. One of these chains *7* is stationary, and is secured by strap *8*. Movable chain *9* can be shifted to suit the dimensions of the stamps or dies. The chain is prevented from slipping by stops *10*.

When it is required to shift or install stamps or dies, the ends of the overhead travelling crane chains are secured to hook *4*; the die or stamp is then lifted with the aid of lifting rods *11* and chains *5* and installed on the hammer.

Changing Packing and Repairing Glands. Convenient and stable ladders are required when replacing gland packings or repairing glands. Usually, ordinary portable ladders are employed, but they are unstable and workers frequently fall from them. Folding ladders with platforms are best and should be used wherever possible.

Miscellaneous Maintenance Work. Before commencing any kind of maintenance work, the personnel must be properly instructed, so as to avoid accidents.

CHAPTER IX

FORGING OPERATIONS AND HAMMER FORGING TOOLS

THE PRINCIPAL FORGING TOOLS

Dies. Dies are the chief forging tools. The metal is deformed between the hammer dies, the bottom die supporting the work and the various tools employed during the forging operations.

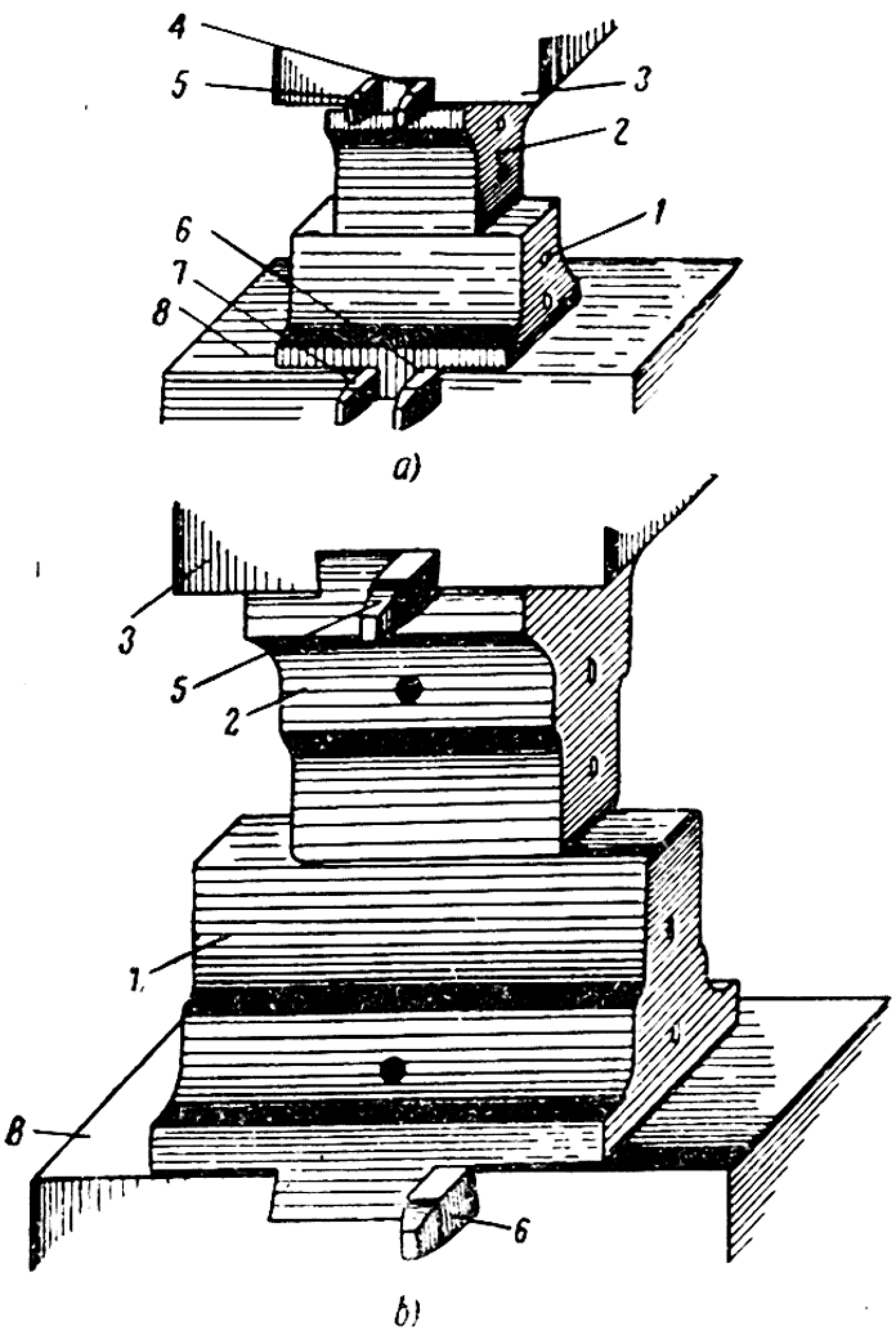


Fig. 180. Attachment of dies

Dies are used in pairs—top and bottom dies (Fig. 180). The top die *2* is fitted to the ram, and the bottom die *1* to the sow-block *8* by means of dovetails, and both are held in place with keys *4*,

5, *6* and *7*; they are likewise locked to prevent longitudinal movement with the aid of dowel or locking pins. In single-frame hammers, when the frame hinders the removal of the keys, bottom die *1* and top die *2* are secured from both sides (Fig. 180, *a*), the top left-hand key *5* being driven into the dovetail with its thin end towards the blacksmith, and the right-hand key *4* with its thin end towards the frame. When replacing dies, the left-hand key is driven out first, after which the right-hand key, having been thus loosened, can be taken out by hand. In other hammers the dies are secured in place by one key only (Fig. 180, *b*). A groove for the dowel pin is machined in the centre of ram *3* and sow block *8*.

The shape of each die is determined by the purpose for which it is designed. In hammers for hammer forging the top die is usually made with a flat working surface. Bottom dies are made in three designs: flat, recessed and saddle dies. The *flat bottom die 1*, together with its flat top die *2* (Fig. 181, *a*) are universal forging tools and are employed for many forging operations: for drawing, upsetting, for punching holes, etc.

The *recessed bottom die* (Fig. 181, *b*) is a special forging tool. It is employed only for forging round work such as, for instance, railway car axles. The die for rolling (saddling) rings, called a *saddle* (Fig. 181, *c*) is also a special forging tool and is only employed for this purpose.

When a forging job calls for both a recessed bottom die and a flat bottom die the *combined die* designed by P. Levandovsky should be substituted for them (Fig. 182). This combined die obviates the necessity for changing dies. In this case flat die *1* serves as a support for recessed die *2* when the latter is needed. When carrying out forging operations needing only flat bottom dies, the work is done without insert *2*. For drawing operations which have to be executed in recessed dies, insert die *2* is placed on flat die *1*, thus transforming it into a recessed die.

The recessed die is secured in place on flat die *1* by means of guide pins *3* (see Fig. 182) inserted into the hole of flat die *1*, the diameter of the hole being about 20 mm larger than that of the guide pin, to exclude any possibility of the latter sticking in the hole. The diameter of the pin holes is smaller at the bottom than at the top, and they have an outlet *4* in the side of the die to facilitate the extraction of scale. When it is necessary to work with flat dies, recessed die *2* is removed.

Dies are generally forged out of grade 30 and grade 50 carbon steel, and are not hardened. Their working surfaces must be made with rounded edges, since sharp edges will lead to cold shuts and are liable to cut the fibre of the metal when reducing (drawing) the forgings. In smith hammers, the bottom dies are generally made longer than

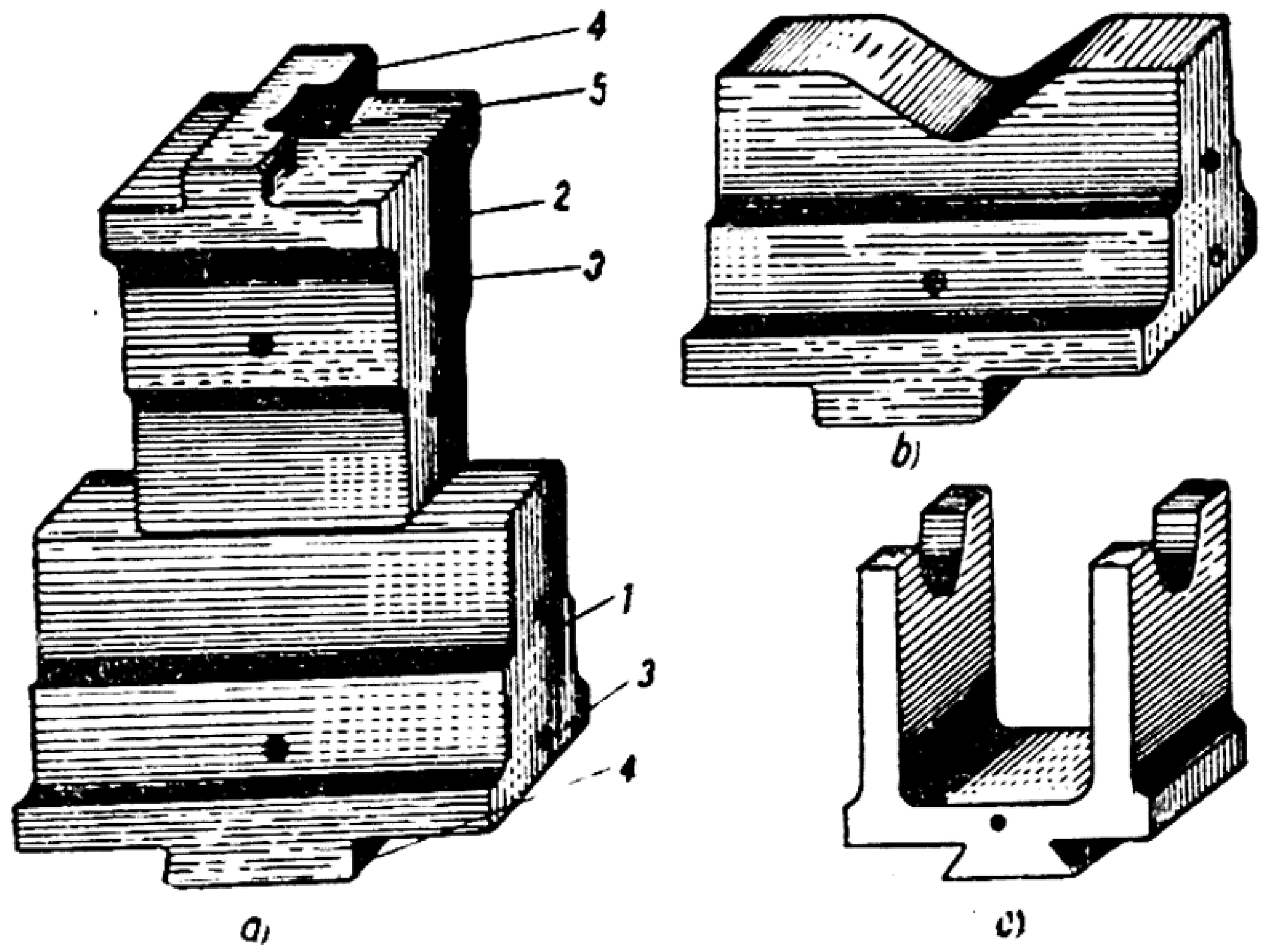


Fig. 181. Hammer forging dies:
1) **bottom** die; 2) top die; 3) handling holes; 4) dovetail; 5) dowel groove

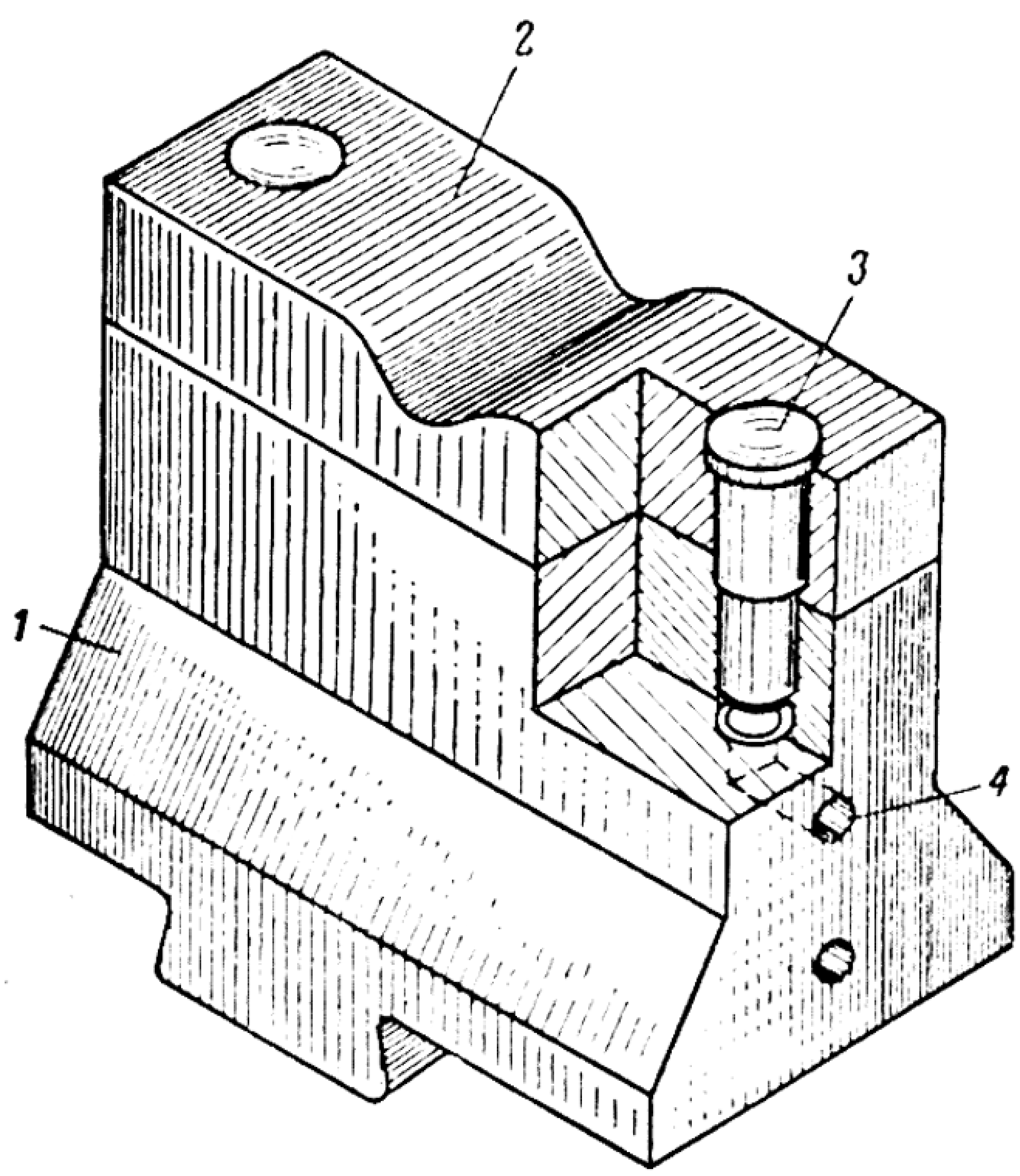


Fig. 182. Combined die for forging hammer

the top ones. This facilitates the location of the various implements on the dies during forging, such as: saddles, inserts, insert dies, etc., and also makes for greater convenience in straightening long forgings, such as shafts. However, the width of the top and bottom dies must always be the same.

The working surface of the dies must always be absolutely smooth, without any visible dents. The entire working surface of the top die must be absolutely flat and, when lowered onto the bottom die, must make perfect contact with the latter. Insufficiently close contact between the faces of the top and bottom dies may be due to their incorrect machining, improper installation of the anvil block, and other causes.

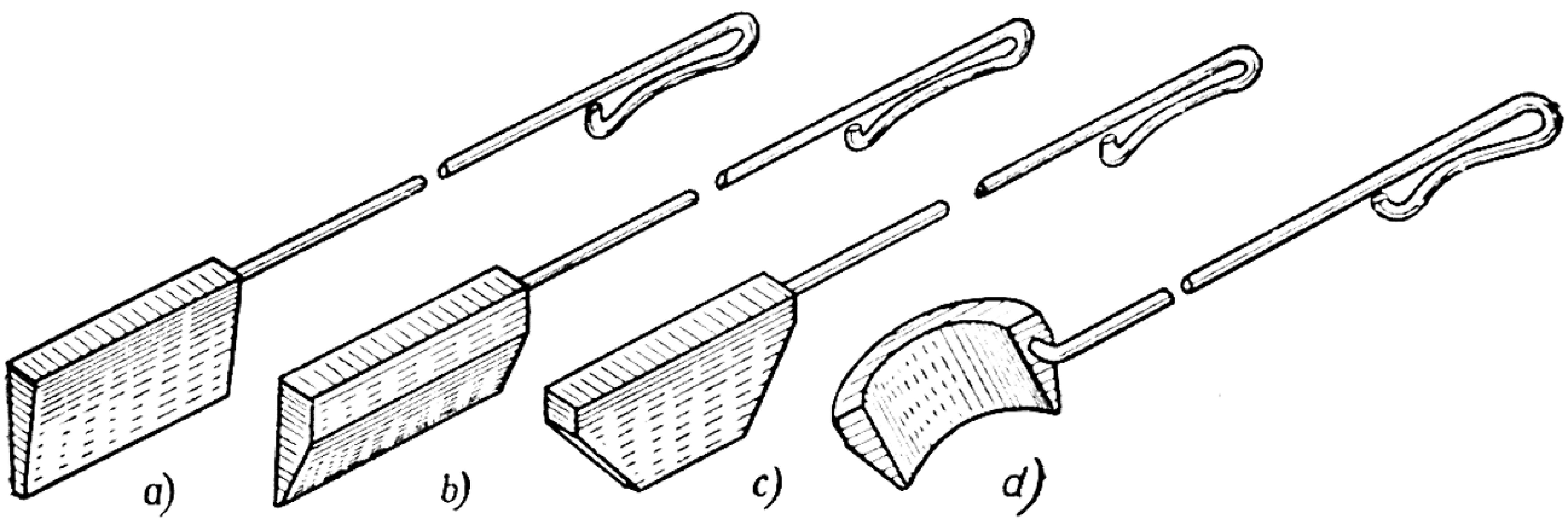


Fig. 183. Blacksmith's hot sets

The width of the die is selected to suit the capacity of the hammer, as, the wider the die, the less energy will be transmitted by the impact to each unit of area of the metal which is to be worked. Recessed dies are made from 15 to 20 per cent wider than flat dies, as, when forging between such dies, the metal contacts a smaller area of the working surface of the die than when forging in flat dies.

Hot Sets. Hot sets are used for cutting metal. Fig. 183 illustrates the types of hot sets most commonly used in forging practice. *Single-sided hot sets* (Fig. 183, *b*), having a cross-section in the shape of a rectangular trapezium, are used when it is required to cut stock so that the cut end is perfectly smooth and square.

Double-sided hot sets (Fig. 183, *a*), having a cross-section shaped like an equilateral trapezium, are also used for cutting stock; when they are used the ends of the cut stock will not always be square.

Fig. 183, *c*, shows a hot set employed for cutting round bars on recessed dies. Such a hot set damages the surface of recessed dies less than others. Fig 183, *d*, illustrates a shaped hot set.

Hot sets are made of grades 40 and 50 carbon steel, while those of large size are made of grades 5XHM, 5XΓM and other grades of steel.

The handles of hot sets are made of grade 15 or grade 20 carbon steel, and are either forged together with the hot set from a single piece of steel, or separately, from a steel rod. after which they are

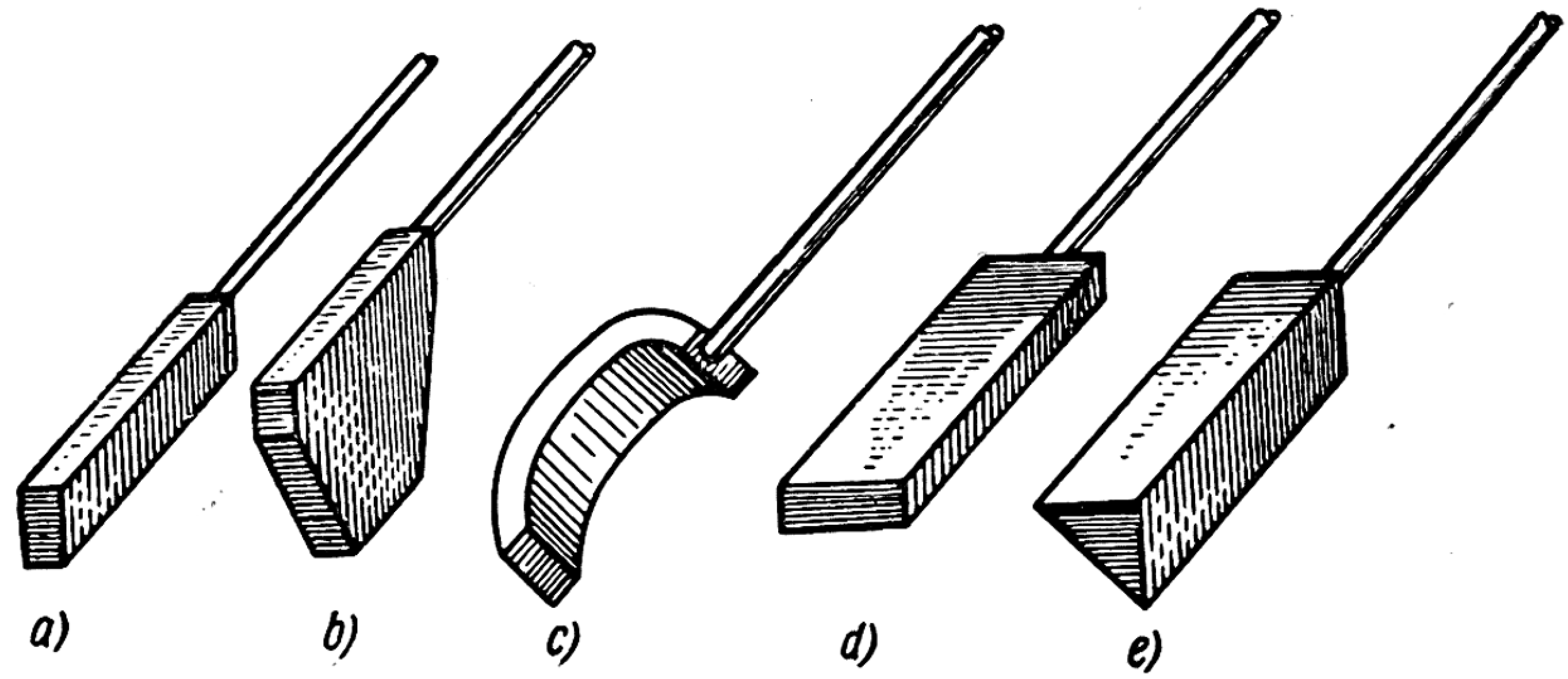


Fig. 184. Cutters:
a) square cutter; b) cutter used with recessed dies; c) half-round cutter; d) flat square cutter; e) side cutter

attached to the set. Separate handles, forged from rods, are however preferable, particularly for the larger hot sets. Hot sets are heat-treated (hardened with subsequent tempering) in order to prolong their life. They must be cooled from time to time in the course of work.

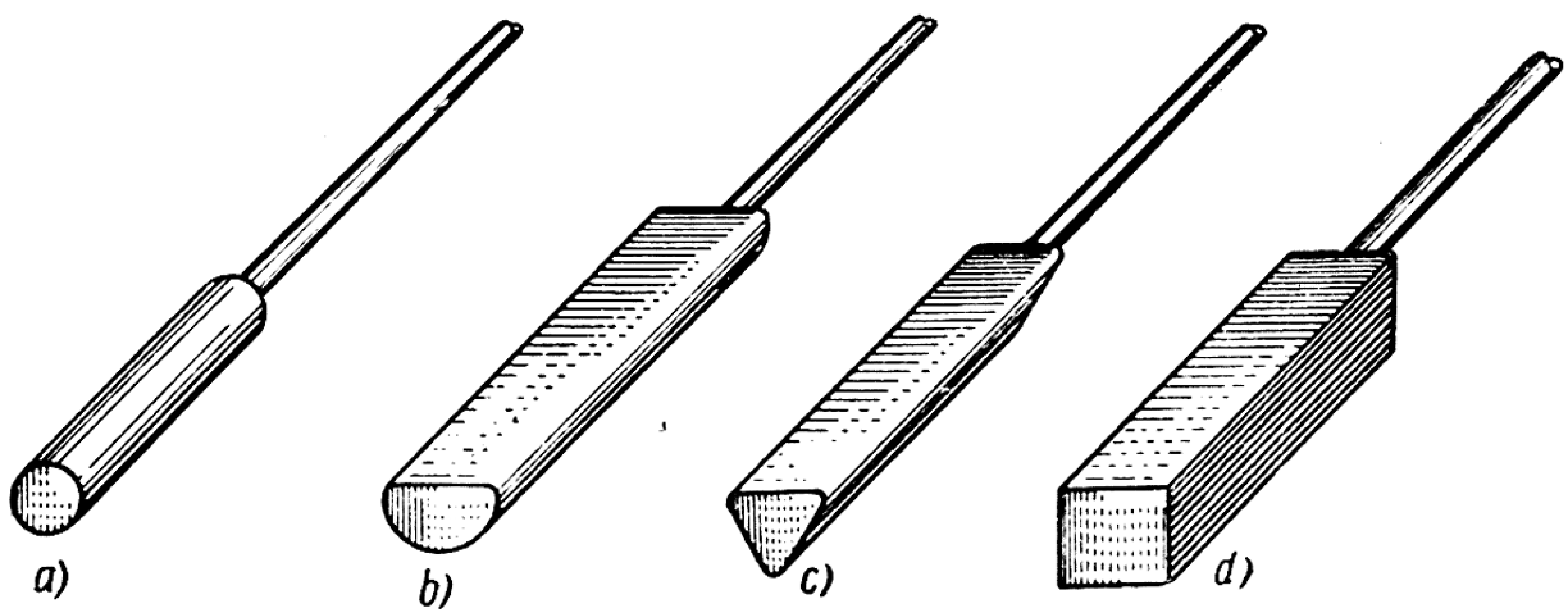


Fig. 185. Setting tools:
a) round set; b) oval set; c) side set; d) square set

Cutters. Cutters are used as auxiliary tools when cutting and as extensions for cutting off burrs, when the height (thickness) of the forging is greater than that of the hot set, and in other cases. Fig. 184 shows the most commonly used types of cutters. They are made of grade 35 or 40 carbon steel, and their handles—of grade 15 or 25 carbon steel.

Setting Tools. Setting tools (Fig. 185) are used chiefly for heavy forgings and are made in various sizes. They are used much in the same way as fullers, i. e., for the first forging operation—for marking the limits of the sections of a forging. They are made in various shapes, as illustrated in Fig. 185—round, oval, triangular (called side-sets) and square. If, for instance, it is required to draw out one end of a square bar to a round section, the tool is set on the bar at the point where reduction is to begin, and forced to a slight depth into the bar with a hammer. The setting tool will thus make notches in the bar to indicate the boundaries between the different sections of the forging.

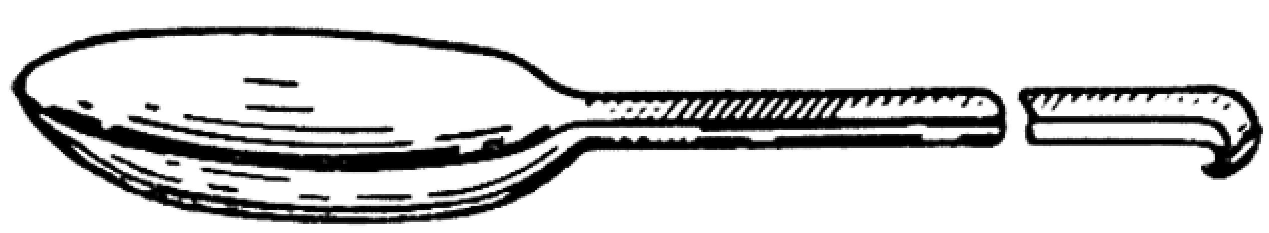


Fig. 186. Spoon fuller

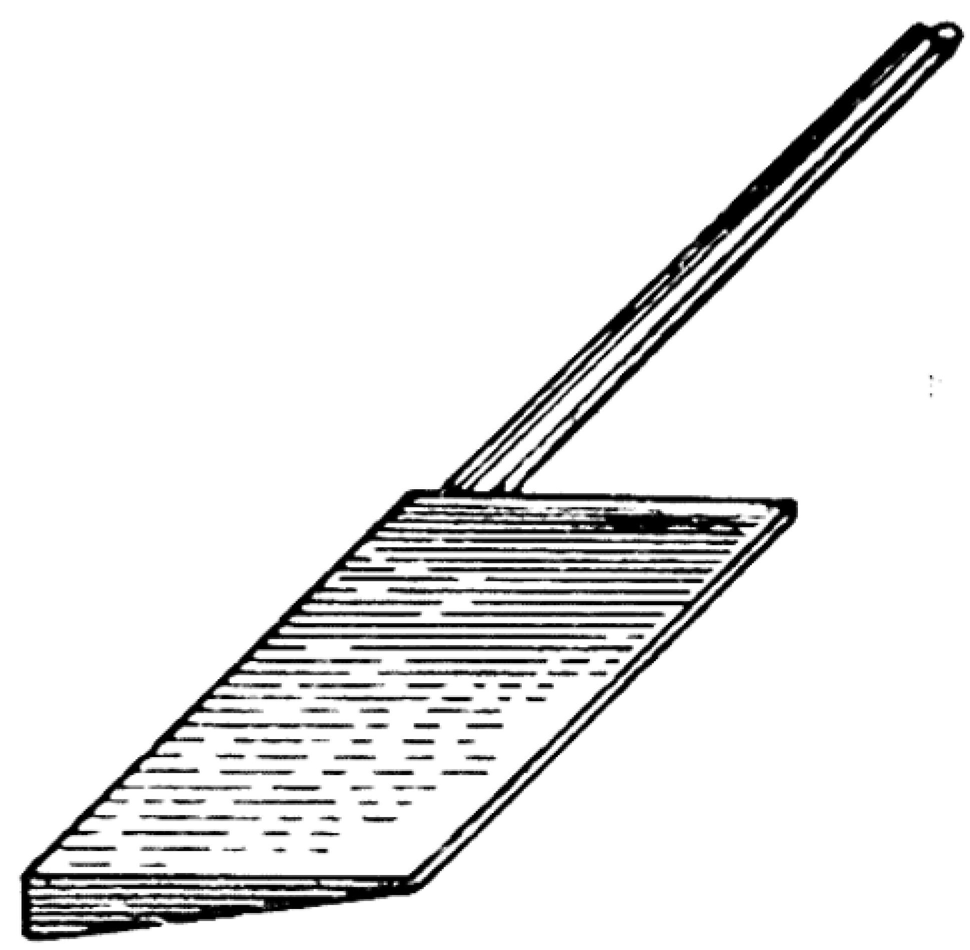


Fig. 187. Tapered set

These tools are made of grades 35 and 40 carbon steel; their handles—of grades 15 and 25 carbon steel. Small sets are forged together with their handles.

Fullers. Fullers or spreaders, as they are sometimes called, are used for drawing-out (reducing) heavy forgings to smaller cross-sections, if the distance between the shoulders and flanges is less than the width of the dies. In such cases, flat fullers are used for reducing the cross-section of the stock.

Fullers are made in various cross-sections and dimensions to suit the stock with which they will be used. Setting tools are often used as fullers. When drawing-out large flat surfaces both in length and width, spoon-shaped fullers, as shown in Fig. 186, are used. They are called spoons because of their shape. Fullers are made of grade 35 or 40 carbon steel; their handles are made of grade 15 or 25 carbon steel.

Tapered Sets. Tapered sets (Fig. 187) are used for finishing operations when making tapered forgings. They are used in pairs, and are made with various angles, not exceeding 20° between their broad sides. One tapered set is placed on the bottom die of the hammer, and the other—on top of the forging. The hammer strikes the top set.

Work is usually rough taper forged between flat dies without tapered sets.

Swages. Swages as shown in Fig. 188 are used for rounding and smoothing forgings to the required size. The stock is inserted in the bottom swage, which is placed on the hammer anvil, and the top swage is struck with the top die; during forging, the stock must be constantly turned within the swage after each blow, and moved back-

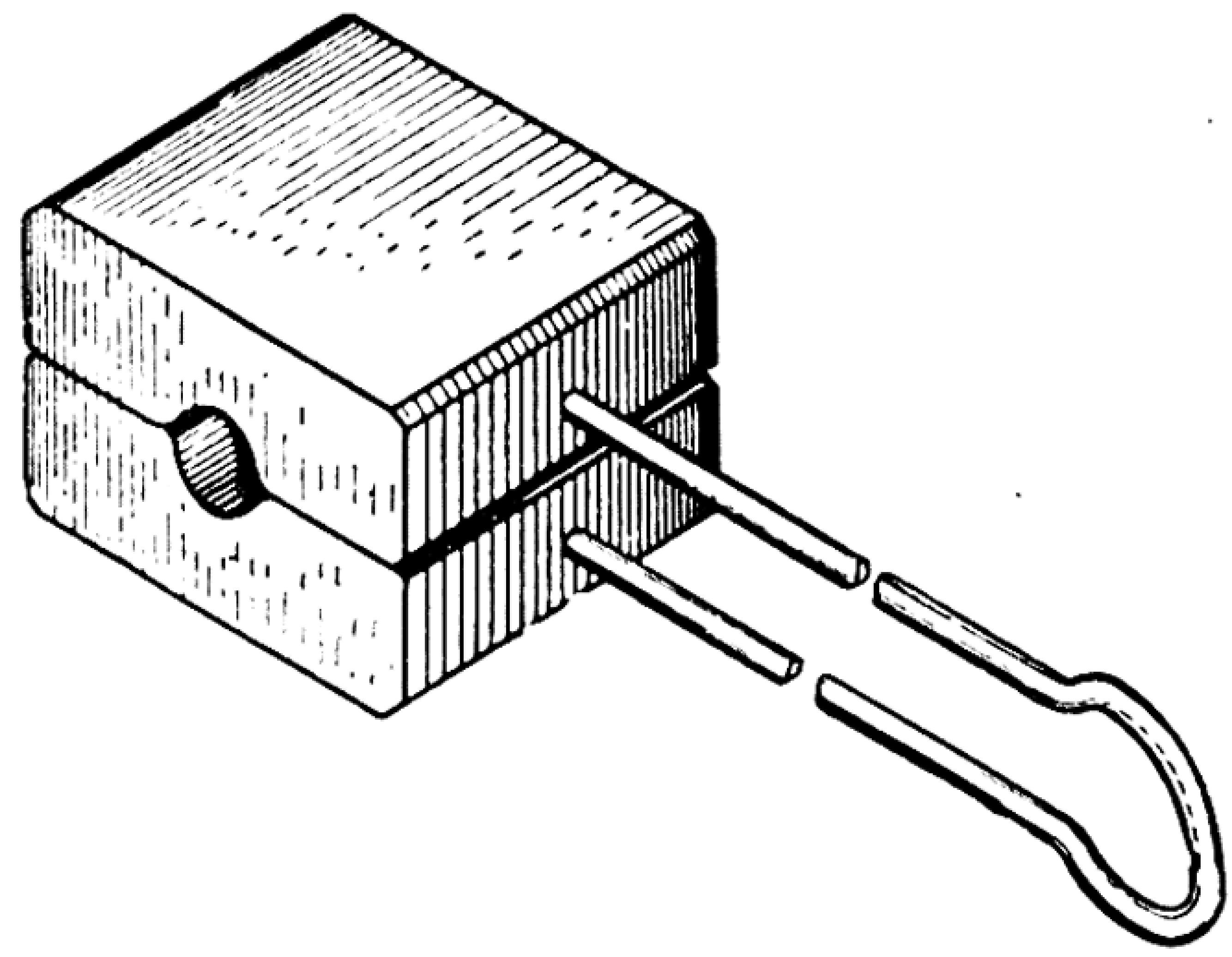
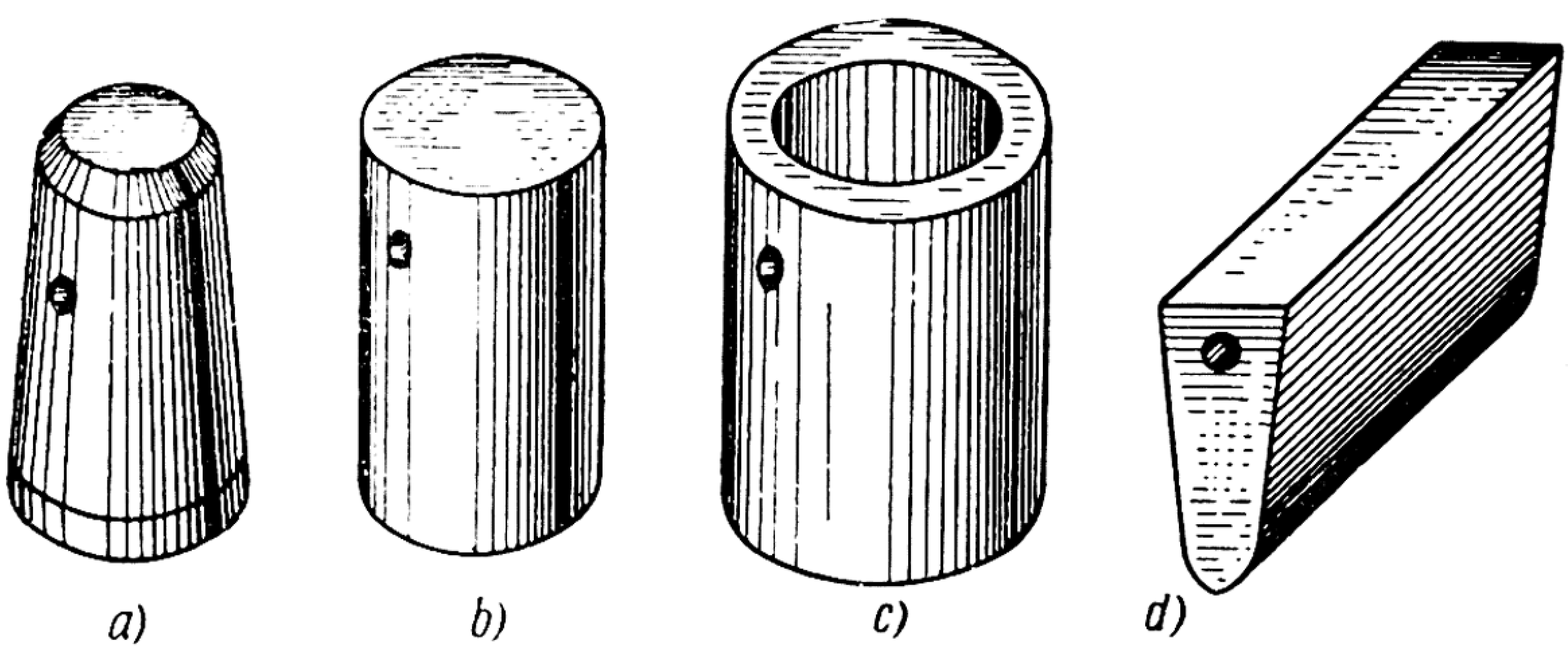


Fig. 188. Swage

wards and forwards. Forging in swages gives the stock a smooth surface and the correct cross-section. Swages are made of grade 50 carbon steel, and their handles—of grade 15 or 25 carbon steel; small



a) b) c) d)

Fig. 189. Punches:
a) tapered punch; b) cylindrical punch; c) hollow punch; d) wedge punch

swages (with recesses up to 50-60 mm in diameter) are made in pairs with a common handle shaped like a spring yoke, as shown in Fig. 188. The dimensions of swages are calculated according to the following considerations: if the diameter of the working part of the swage is D, its width will be from 2 to 3 D, its length from 3 D to 5 D, and the thickness of each swage will vary from 1.5 D to 2 D. Swages can

be made with working parts (recesses) of round, square, hexagonal and other cross-sections.

Punches. Punches are used for making holes (Fig. 189). They are usually made of grade У7 carbon tool steels.

FIXTURES AND AUXILIARY TOOLS

Blacksmiths often have to handle heavy forgings weighing up to several hundred kilograms each. Many different types of fixtures and arrangements are used for lightening the work of the blacksmith and for increasing his productivity.

These fixtures and arrangements can be divided into *two groups*, depending on the kind of work for which they are to be used: 1) those used for gripping, supporting and shifting the stock during the process of hammer forging; 2) handling (transporting) fixtures and arrangements designed for transporting stock and forgings in the shop,

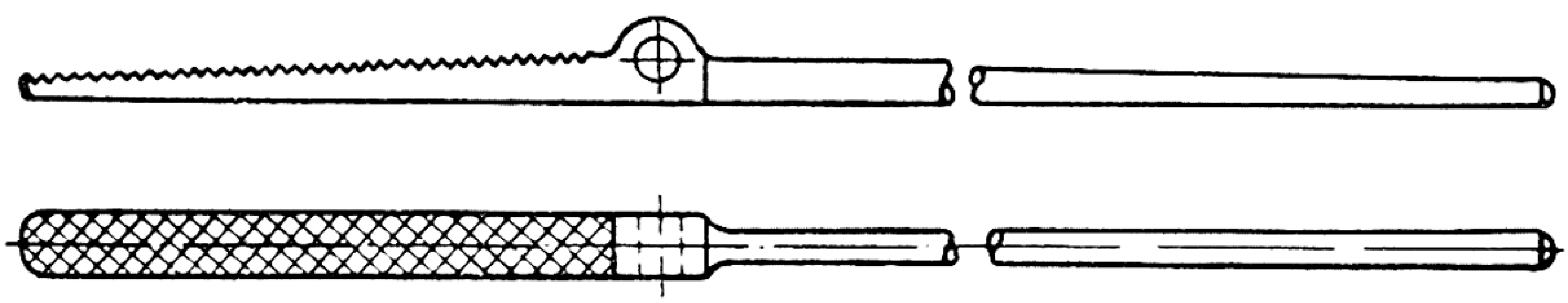


Fig. 190. Pinch-bars for handling wagon axle forgings

for charging them into furnaces, and for delivering them from the furnace to the hammer. We will first discuss the first group—fixtures for handling stock during its forging.

Tongs. Tongs serve for gripping, holding, turning and shifting the metal and tools during forging operations. The tongs used in hammer forging are of the same design as those used for hand forging.

Pinch-Bars. Pinch-bars (Fig. 190) are used for turning the stock during the process of hammer forging. Sometimes two suspended pinch-bars are used, when forging long and heavy work. Fig. 191 illustrates the process of forging an axle with two such pinch-bars.

Portabars. Portabars are used for handling and turning heavy forgings and for withdrawing heavy stock from furnaces. They consist of a pair of clamps with long handles bolted together, as illustrated in Fig. 192; they are used for handling square-section forgings, and by adjusting the distance between the clamps one portabar can be used for forgings of different sizes. When working with portabars, care must be taken that the tie-bolts are properly drawn up as otherwise the portabar may fall on the feet of those handling it.

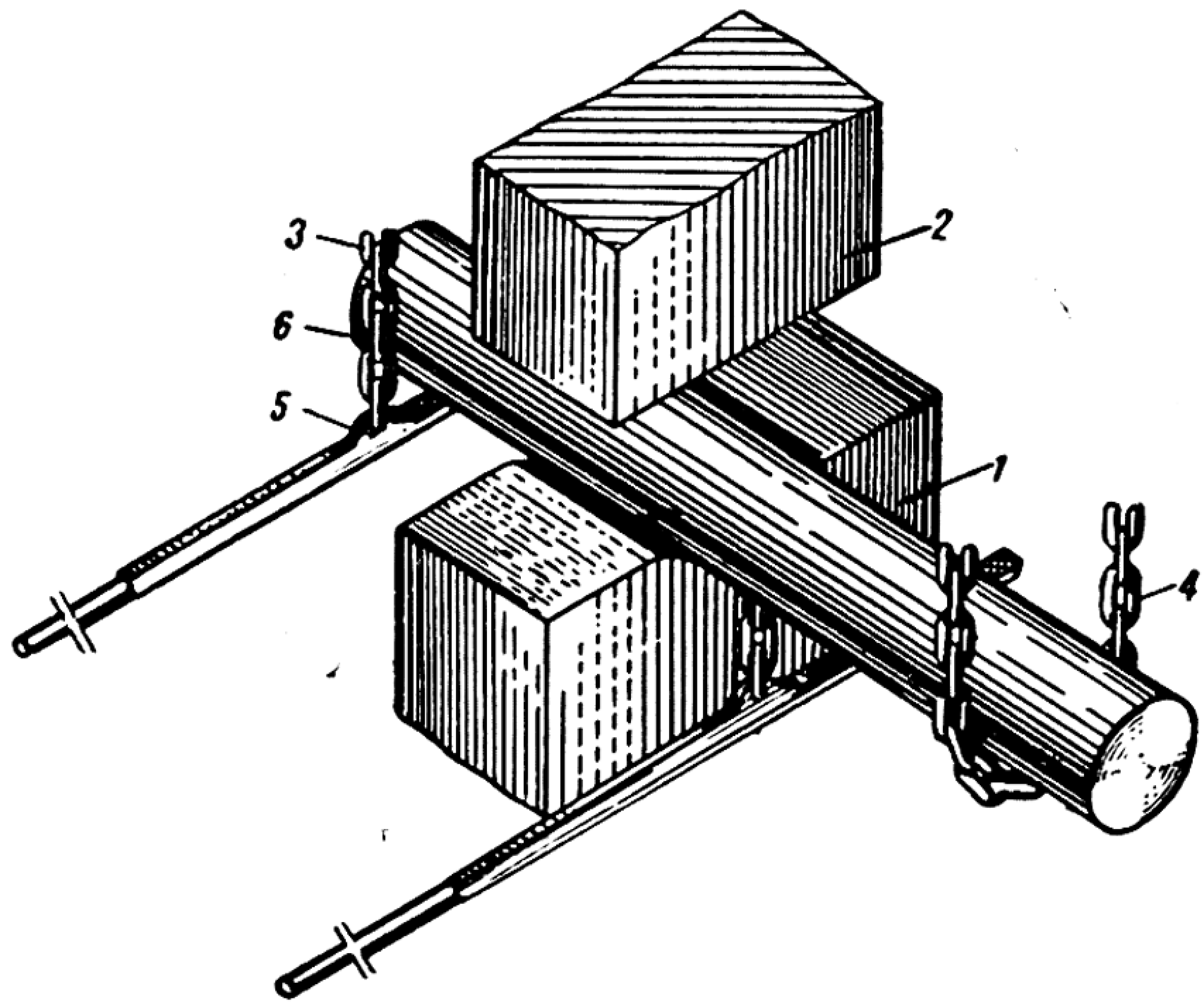


Fig. 191. Forging a shaft with pinch-bars:
1, 2) bottom and top dies; 3) chain for suspending pinch-bar; 4) crane chain; 5) pinch-bar; 6) forging (shaft)

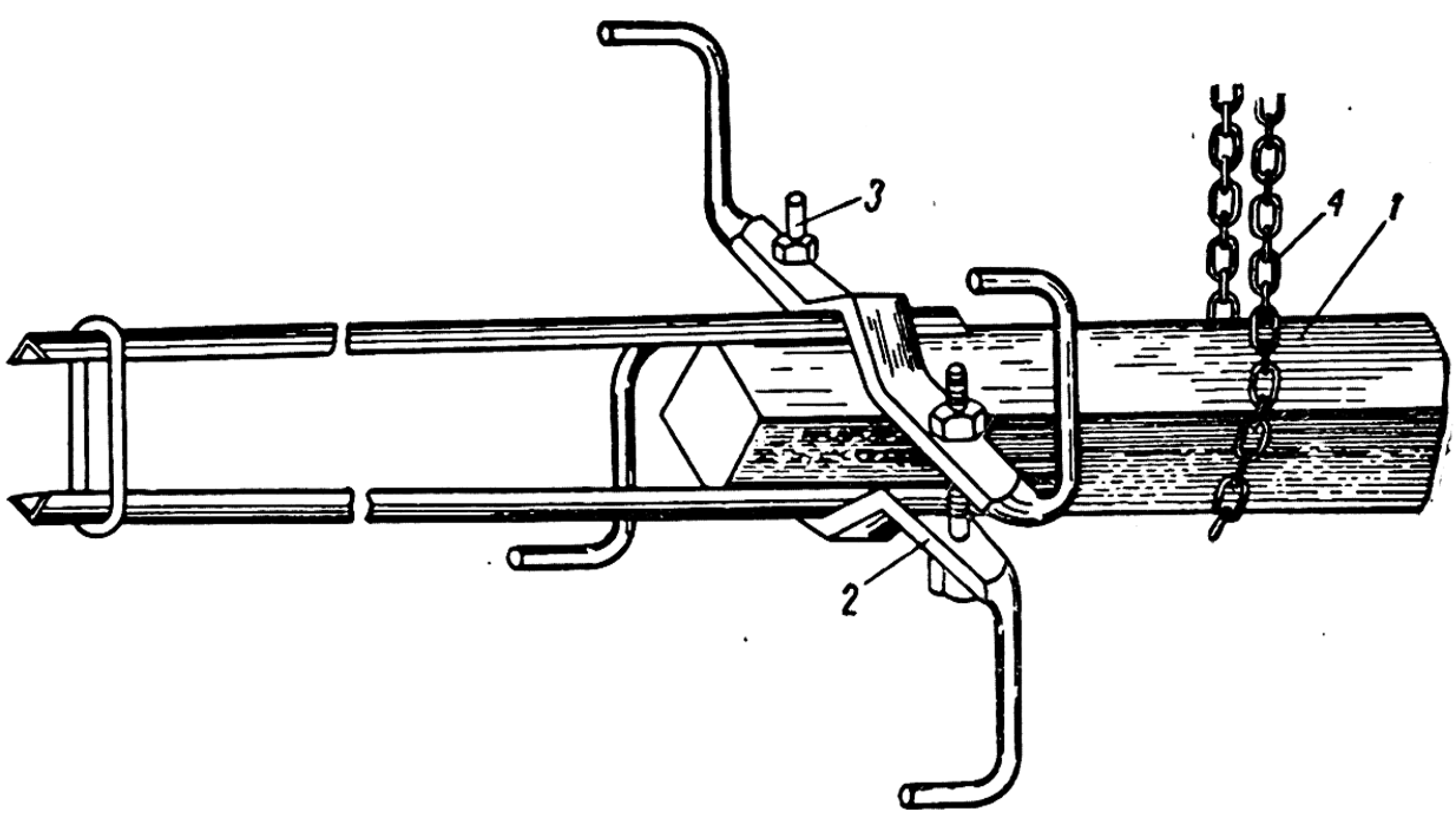


Fig. 192. Portabar:
1) forging; 2) portabar; 3) tie bolts; 4) crane chain

Chucks. Chucks (Fig. 193) are used for turning stock when considerable quantities of duplicate forgings such as, for instance, railway wagon axles are being made. For this purpose, chuck *1* is inserted over the end of stock *2* and secured in place with bolts *3*. The chucks can be rotated inside ring *5* suspended from chain *6*.

In addition to the above-mentioned fixtures, long and short bars are also used for shifting forgings between the dies.

As was previously mentioned, handling and transporting devices fall into the second group.

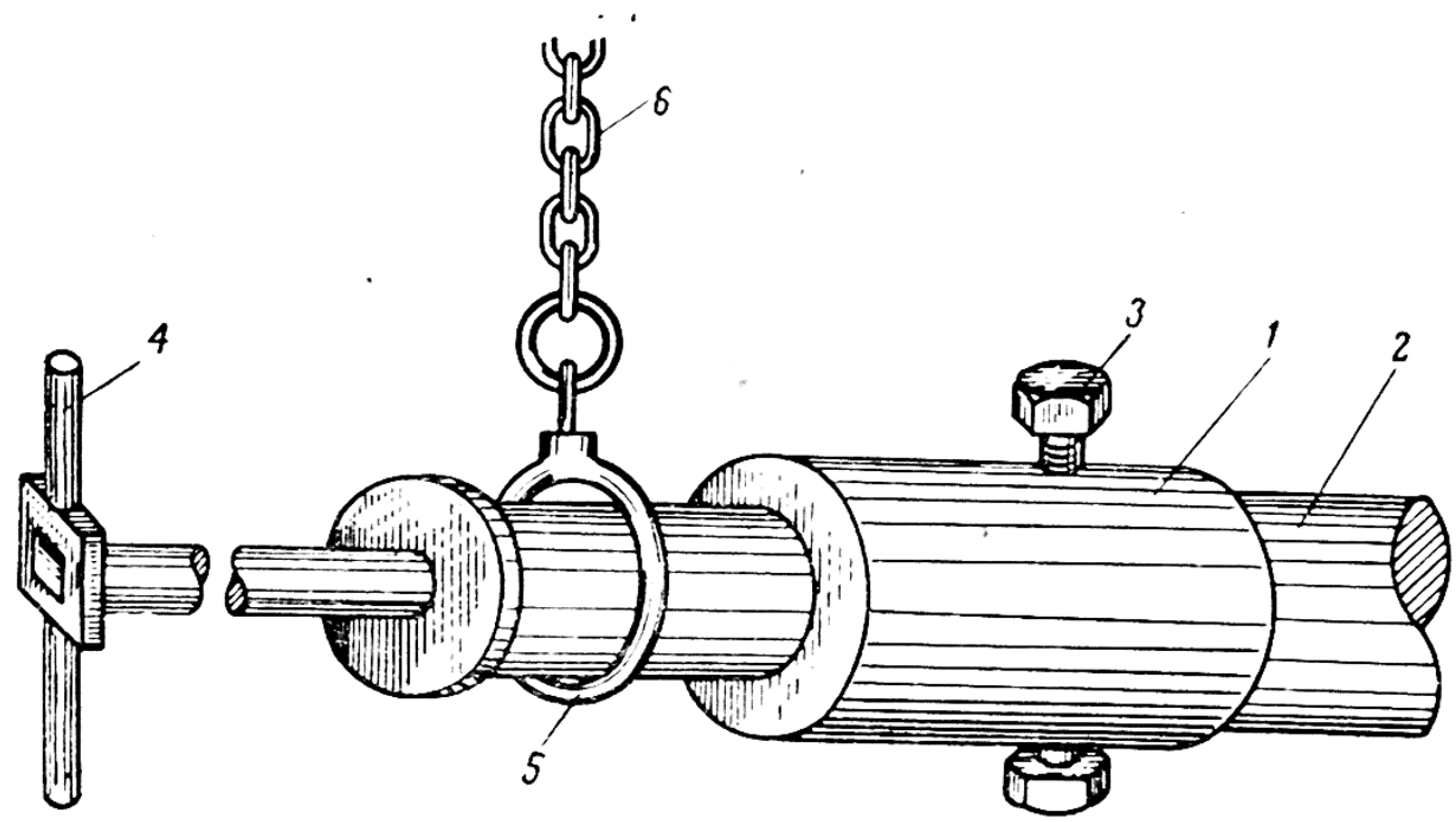


Fig. 193. Chuck

Let us discuss some of these devices.

Bar hand tongs are used for handling and transporting short heavy pieces of stock, as illustrated in Fig. 194.

Self-closing crane tongs (Fig. 195) are used for handling croppings, shaft-type forgings, medium-sized blocks, plates and other forgings and production scrap. For this purpose, the crane is brought near the object to be moved, and the tongs are lowered with arms open to grip the forging. On raising the tongs, the arms will automatically tighten around the work to be handled and lift the load.

Handling tongs for discs, blocks and other forgings comprise a left-hand *2* and right-hand *1* arms, each made of two steel bars, as shown in Fig. 196. The gripping section (jaws) of each arm is connected by plate *3*, and the shoulders—by cross plate *4*. The right-hand jaw is inserted between the bars of the left-hand arm, and connected by axle *5*. The bar of the left-hand jaw is lifted with a guide bar *6*, to the end of

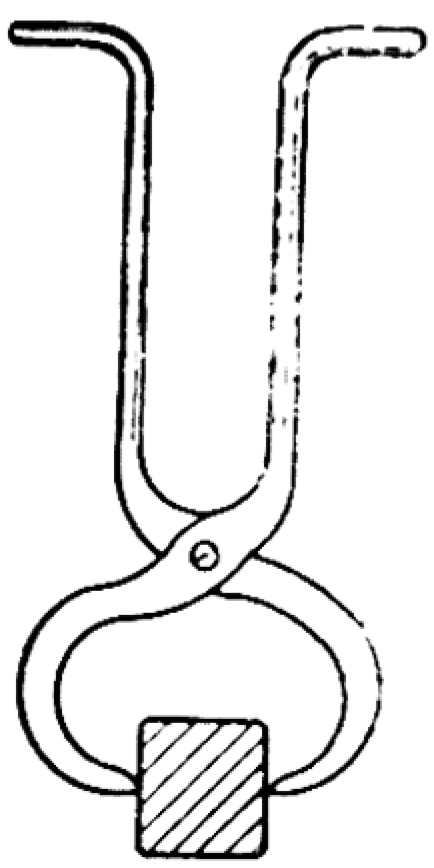


Fig. 194. Hand bar tongs

Fig. 195. Self closing crane tongs

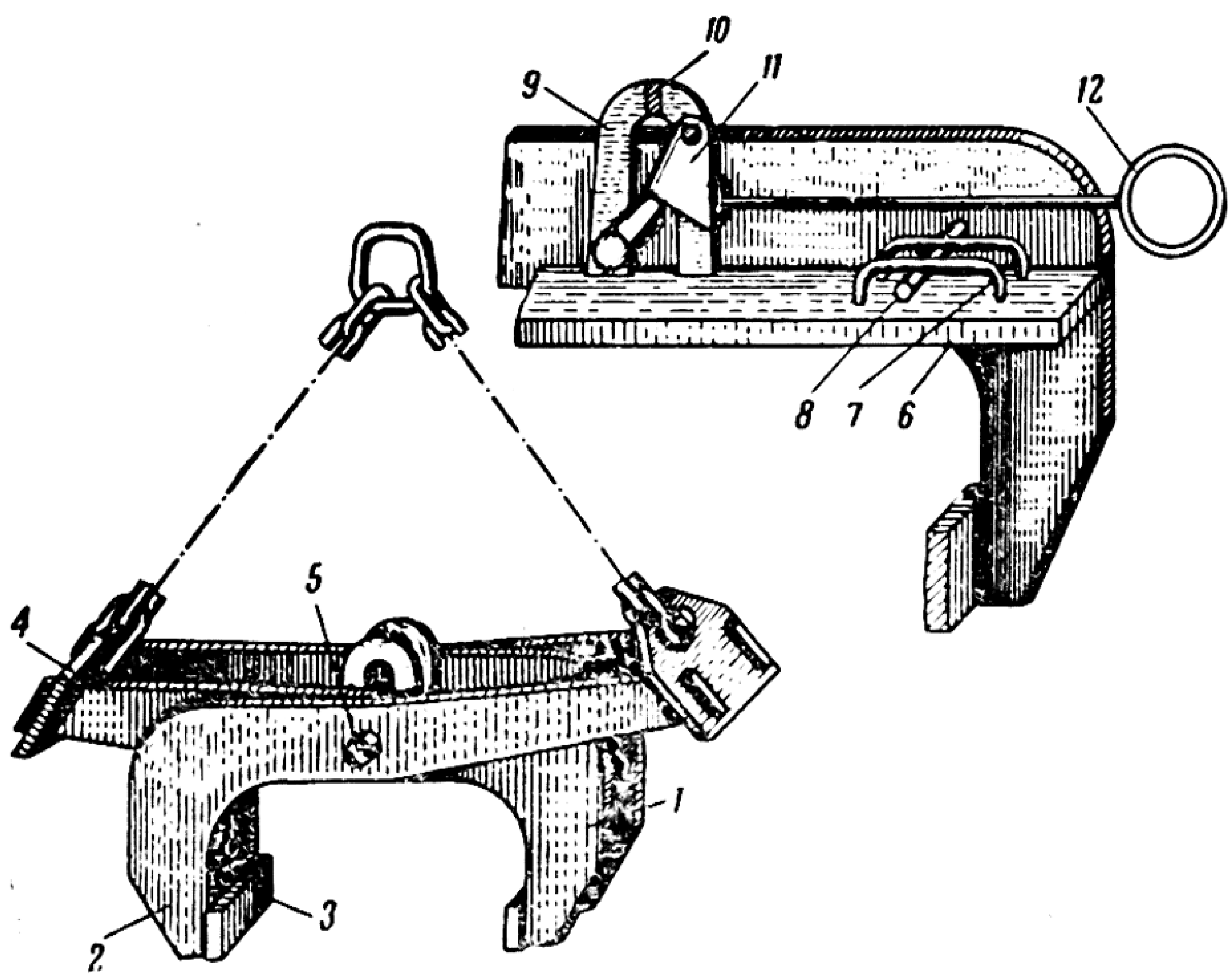


Fig. 196. Disc and block handling tongs

which are welded four shackles *7* for holding bolts *8* of the left-hand and right-hand jaws.

Upright *9*, consisting of two plates separated by rib *10*, is welded in the centre of this fixture. Lock *11* is bolted inside and to the right-hand foot of this support; it is connected to handle *12* by a clamp.

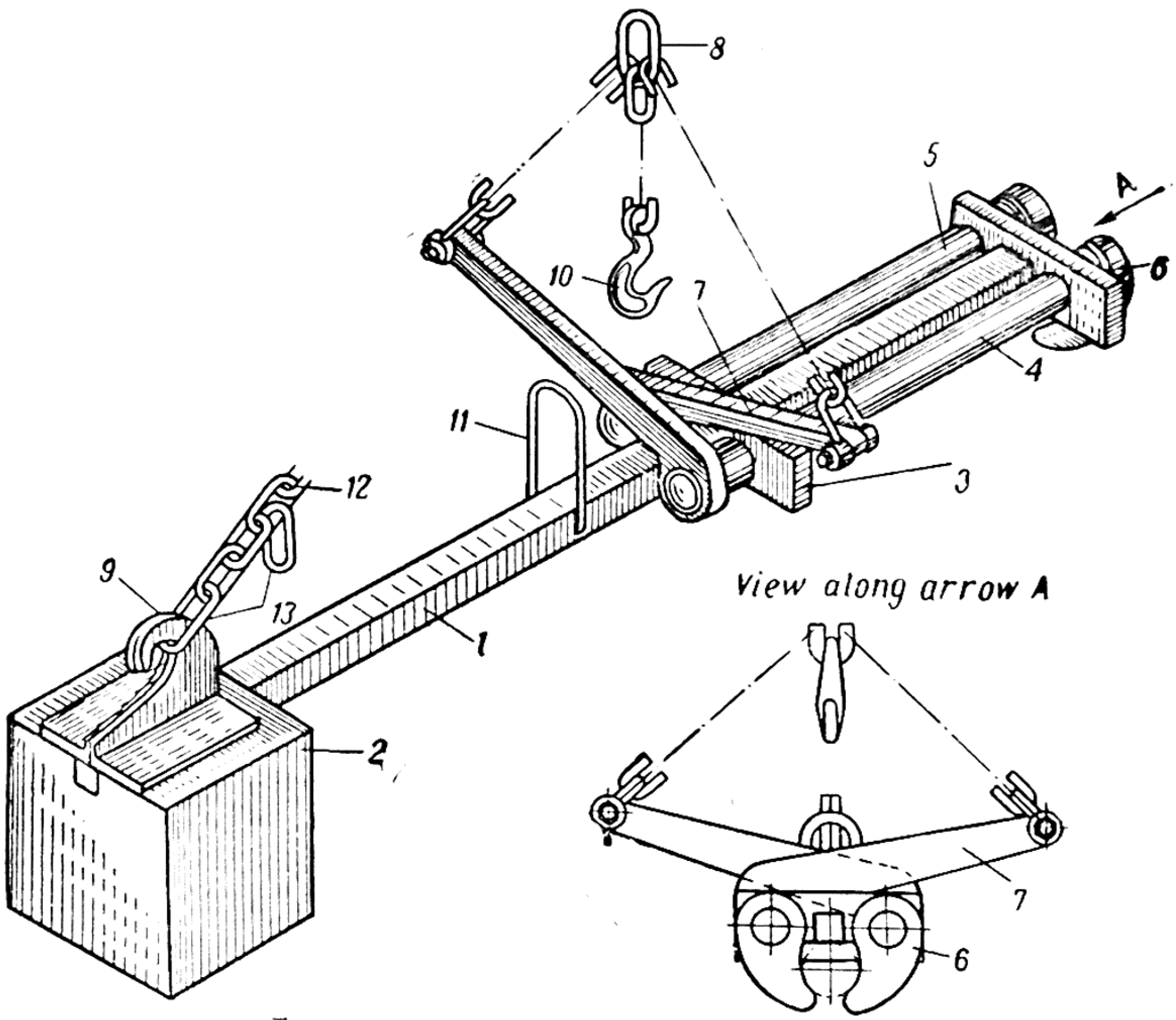


Fig. 197. Charging bar

Before gripping any load, the tongs are always open, as lock *11* prevents axle *5* from moving upwards.

When it is required to transport a load, the tongs must be lowered by the crane onto the load, lock *11* opened with the aid of handle *12*; when the tongs are lifted by the crane, they will grip the load. After the latter has been lowered into position, the lock will automatically resume its initial position, the tongs will re-open and be ready for handling the next load.

The Charging Bar. The charging bar shown in Fig. 197 is designed for charging round and square bars from 500 to 2,000 kg in weight into heating furnaces, and for delivering them from the latter to the bottom die of the hammer.

The charging bar consists of bar *1*, one end of which is inserted into the grooves of counterweight *2*. Cross bars *3* are welded to the opposite end of the bar and in its centre. Right-hand shaft *4* and left-hand shaft *5* are inserted inside these cross bars. Gripping jaws *6* and levers *7* to which hoisting unit *8* is attached are welded to these shafts.

The charging bar is handled in the following way: the hoisting unit is attached to the crane, and the free end of chain *12* is hooked onto counterweight *9*. In order to grip the work, hook *10* must be secured to shackle *11*, thus releasing levers *7*, which open gripping jaws *6* through shafts *4* and *5*. In this position the charging bar is lowered onto the load to be lifted. Then hook *10* is released from shackle *11*, and chain *12* is lengthened to enable its link *13* to be attached to hook *9* of the counterweight, thereby shifting the centre of gravity of the charging bar; in this position the bar is ready to lift the work.

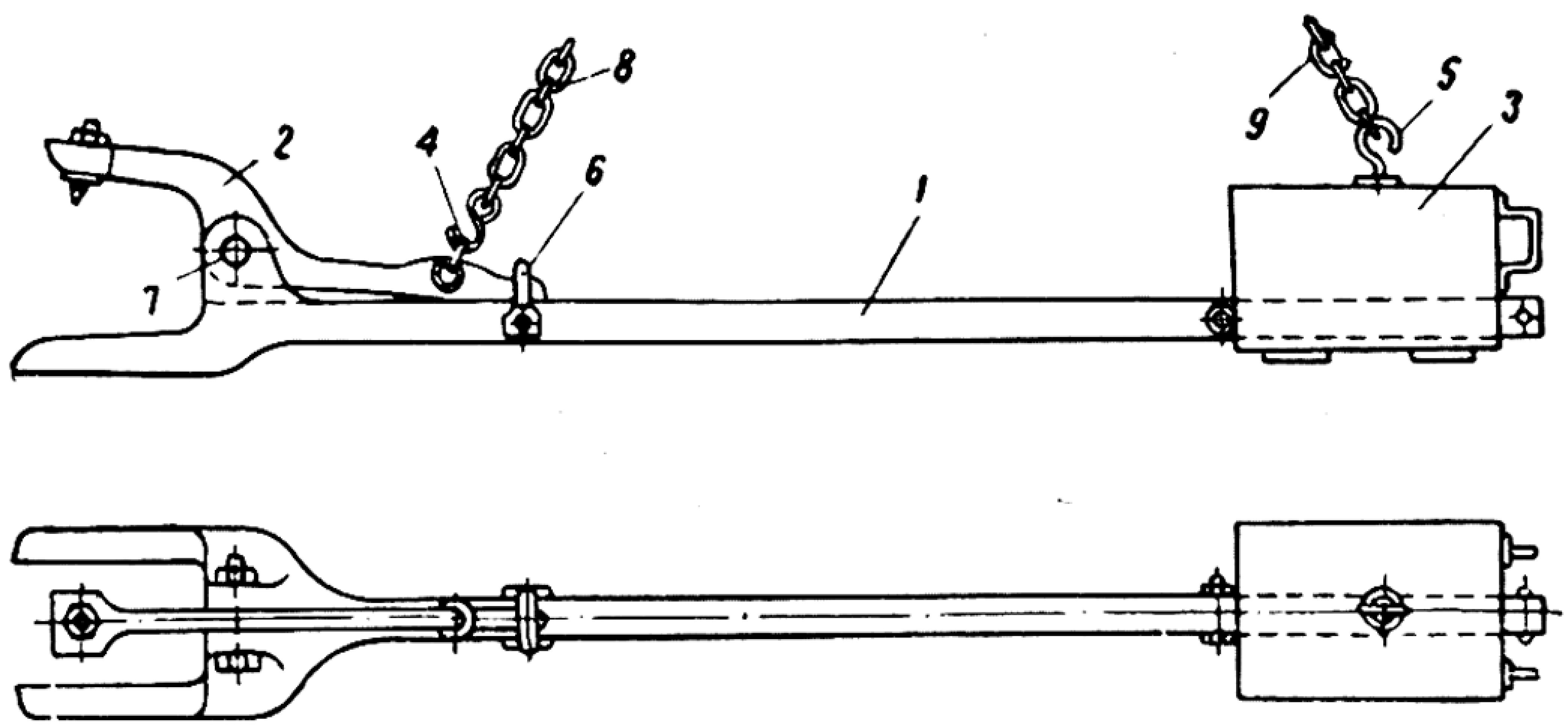


Fig. 198. Furnace charging and discharging lever:
1) fork; 2) lever; 3) counterweight; 4) lever ring; 5) counterweight hoisting hook; 6) shackle; 7) lever shaft; 8) lever chain; 9) counterweight chain

Furnace Charging and Discharging Lever. The device shown in Fig. 198 is designed for charging ingots and blooms weighing up to 2 tons into furnaces, and delivering them to the forging hammers. The fork of this charging lever, as shown in Fig. 198, is placed over the ingot head with the aid of an overhead travelling crane, with its swinging shackle *6* in the upright position locking lever *2*. The counterweight of this fixture is then lowered onto the floor, whereby shackle *6* automatically falls onto the fork, releasing lever *2*; the charging lever is then lifted with the aid of chains *8* and *9* suspended from the overhead travelling crane. When chain *8* is tightened, lever *2* will grip the head of the ingot. In this position, the crane will carry the fixture, together with the ingot, to the furnace and will load it into the hearth of the furnace, as shown in Fig. 199, *a*.

To release the charging fixture, chain *8* is slackened by moving the crane nearer to the furnace and lowering the chain hook. As chain *8* slackens, as shown in Fig. 199,*a*, lever *2* will fall onto fork *1*, after which shackle *6* is placed over lever *2*; the fixture is removed from the furnace in this position.

To withdraw the heated ingot from the furnace and to deliver it onto the hammer anvil or die, the ingot is grasped by the fixture in the position shown in Fig. 198, with shackle *6* thrown over lever *2*. The counterweight end of the fixture is then lowered onto the floor, as shown in Fig. 199, *b*. Shackle *6* will automatically fall onto fork *1*. The counterweight chain *9* is removed from hook *5* and ring *10* of chain *9* attached to hook *5*. In this position the charging fixture is then raised with the aid of the crane. Fork *1* will then grasp the ingot head, lever *2* will close and the entire fixture together with the ingot will be removed from the furnace and delivered to the hammer. Inasmuch as chain *9* is now longer than chain *10*, the end of counterweight *3* will be lower than the ingot, thereby preventing the ingot head from slipping from the fork of the charging fixture.

Bracket Cranes. Bracket cranes are used for delivering metal from heating furnaces to hammers and for supporting work during forging operations. Electric motor-driven bracket cranes are used with forge hammers with falling parts weighing 1 ton and over, which turn the crane around its axis, drive the truck and lift the metal.

Bracket crane control posts must be located slightly above floor level so as to enable the crane operator to follow the operations of the blacksmith.

Forge hammers with falling parts from 0.75 to 1 ton in weight are generally equipped with swivelling bracket cranes. The lifting capacity of the bracket crane must be equal to the weight of the falling parts of the hammer. For instance, a hammer with falling parts weighing 3 tons must be equipped with a 3-ton lifting capacity bracket crane. As distinguished from ordinary-type bracket cranes, which are equipped with hooks, those cranes have a rotating block and endless chain, on which the forging or mandrel is placed. The block and its endless chain are suspended from the crane with the aid of a specially designed spring compensating block, shown in Fig. 200, which absorbs the shocks resulting from the impact of the hammer against the forgings, and protects the crane from breakage and the chain from rupture.

Overhead travelling electric cranes are employed for transporting metal in forge shops.

Special Fixtures Used for Forging Operations. Drawing and cogging ingots, forging axle shafts, etc., are very arduous operations for which various types of manipulators and turning blocks are employed.

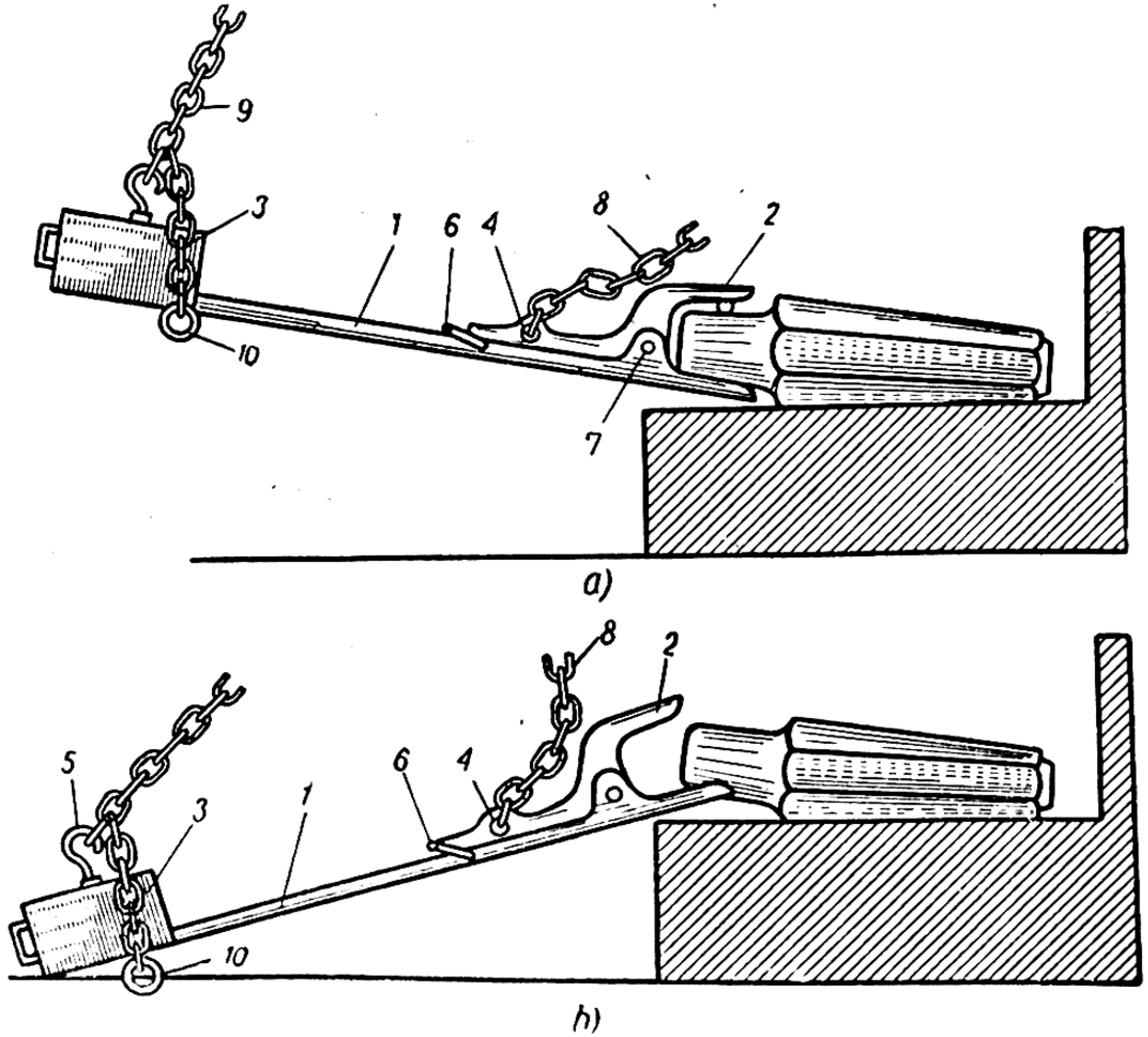


Fig. 199. Charging an ingot into a furnace and discharging it with the aid of the fixture shown in Fig. 198. The figures here refer to the same parts as in Fig. 198

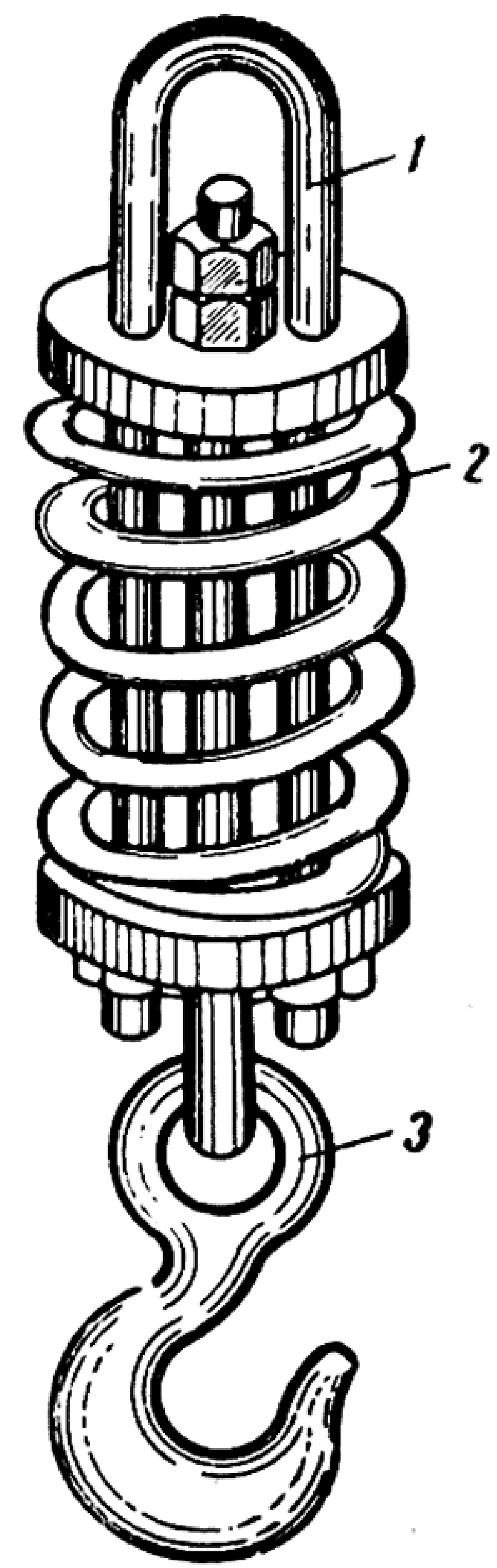


Fig. 200. Spring compensator block:
1) shackle; 2) spring; 3) hook

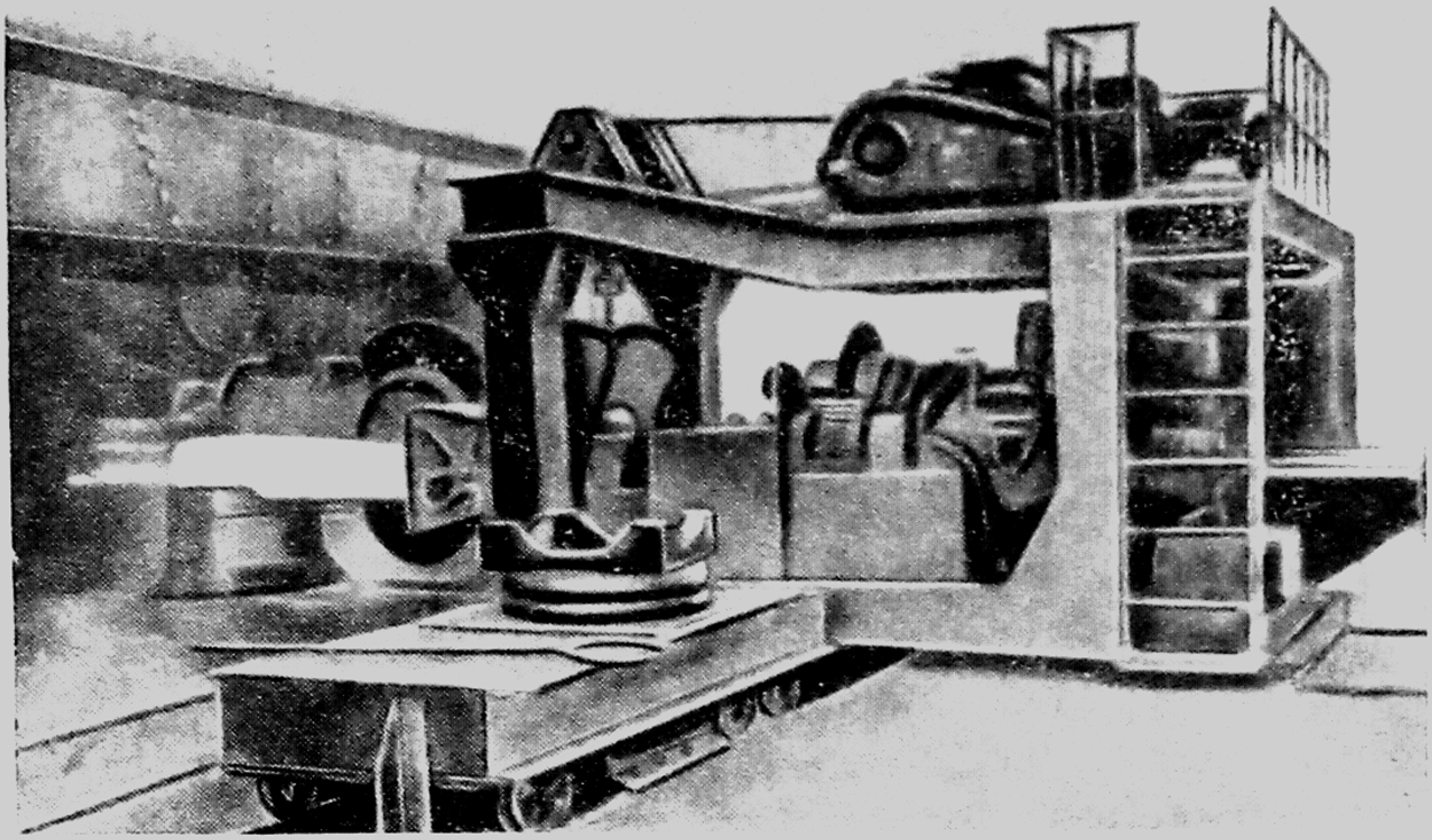


Fig. 201. Forging manipulator

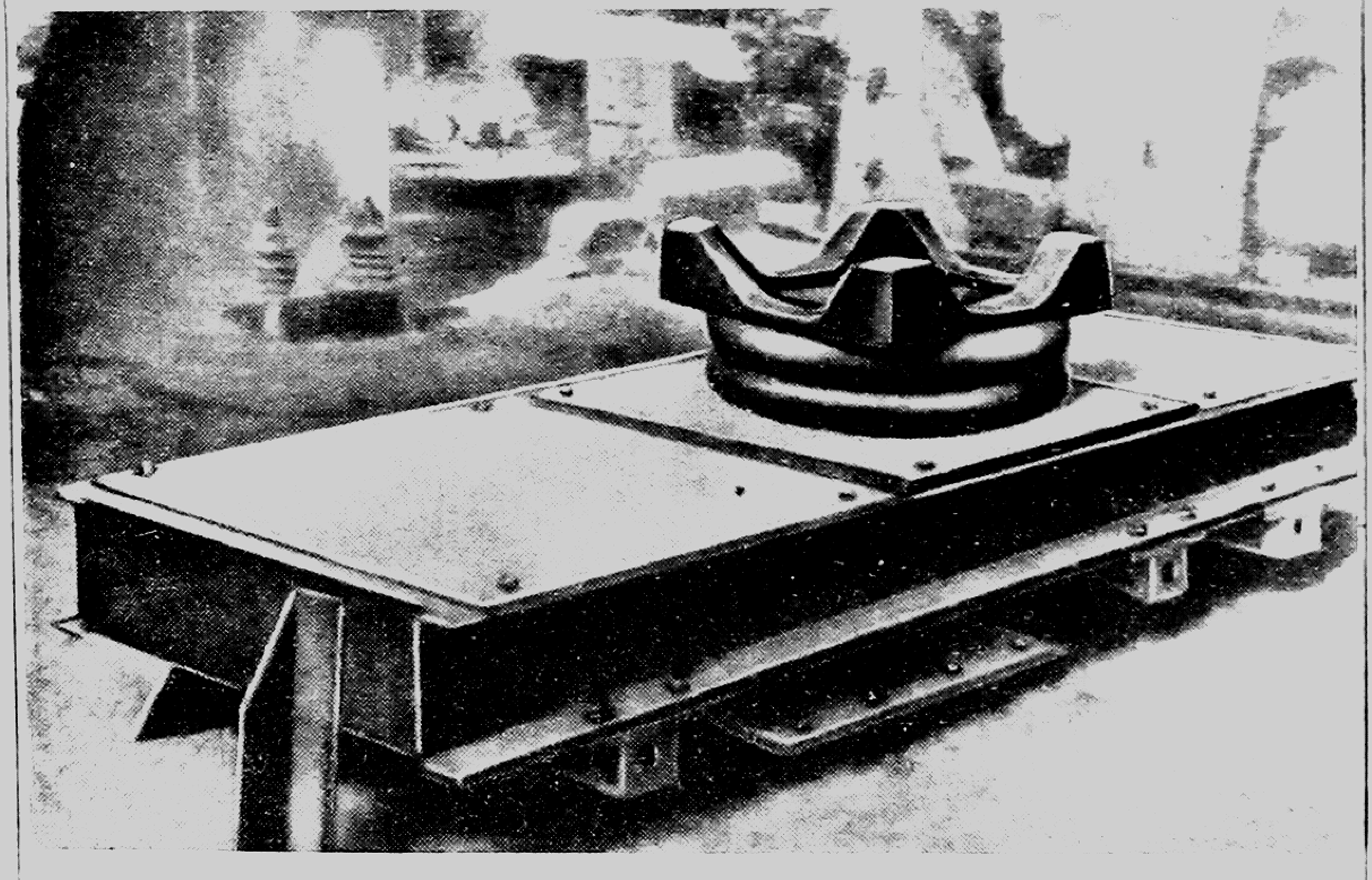


Fig. 202. Car for turning heavy forgings

The travelling *manipulator* shown in Fig. 201 travels from hammer to hammer; the forgings which it handles are rotated by its cantilever arm. Fig. 201 shows a manipulator holding a forging between a flat top and a bottom recessed die during the drawing-out operation. *Electric power trucks* equipped with swivelling platforms are employed for rotating forgings when required (Fig. 202).

With the introduction of automatic hammer controls, manipulators and electric swivelling platform power trucks, all the operations of ingot cogging, shaft forging, ring rolling and other arduous forging operations have been completely mechanised at the Uralmash Works. Here, ingots and other heavy stock are placed on the swivelling platform of the electric power truck with the aid of a charging fixture and delivered to the manipulator. The manipulator grips the work or ingot, places it between the hammer dies and turns it in the required direction.

Saddles of the type shown in Fig. 203 are employed for rolling rings up to 400 mm in diameter. Rings from 400 to 1,000 mm in diameter are rolled on special fixtures as shown in Fig. 204. This fixture consists of base *1*, two uprights *2* and a hinged bottom die *3*. The uprights are secured to the base by hinges; when they are swung back, as shown in Fig. 204, *b*, they are supported by brackets *4* and secured by lock pins *5* to base *1*.

Fig. 204, *a* shows the saddle in its working position, i. e., during the rolling of a ring. In this position the saddle is placed on the bottom die of the hammer, with the ram raised; and saddle die *3* is lifted up until its centre of gravity is beyond the axis of its hinge. The ram then is very slowly lowered, and a special bolster plate is inserted under the saddle; this done, the uprights are raised with the aid of a chain passed over handling rods inserted in holes *6* and, after installation in place, as shown in Fig. 204, *a*, with the aid of the hammer ram, are secured by lock pins *5*. The pierced work is placed over the mandrel with the crane, and then installed on the uprights for subsequent rolling.

On the completion of the rolling operation, the ring is removed from the uprights; the latter are released from their locking pins and are easily lowered onto brackets *4* with the aid of small levers. Saddle die *3* which was lowered during the rolling of the ring, is now inserted into the recess of saddle base *1*; and in this position the edges of the ring are finished on the die, as shown in Fig. 204, *b*.

At the Uralmash Works, the rolling of rings from 400 to 1,000 mm in diameter has been completely mechanised with the aid of manipulators. The ring rolling fixture is rotated through 90°, and the mandrel is turned by the manipulator. Rings of the same diameter are rolled two at a time.

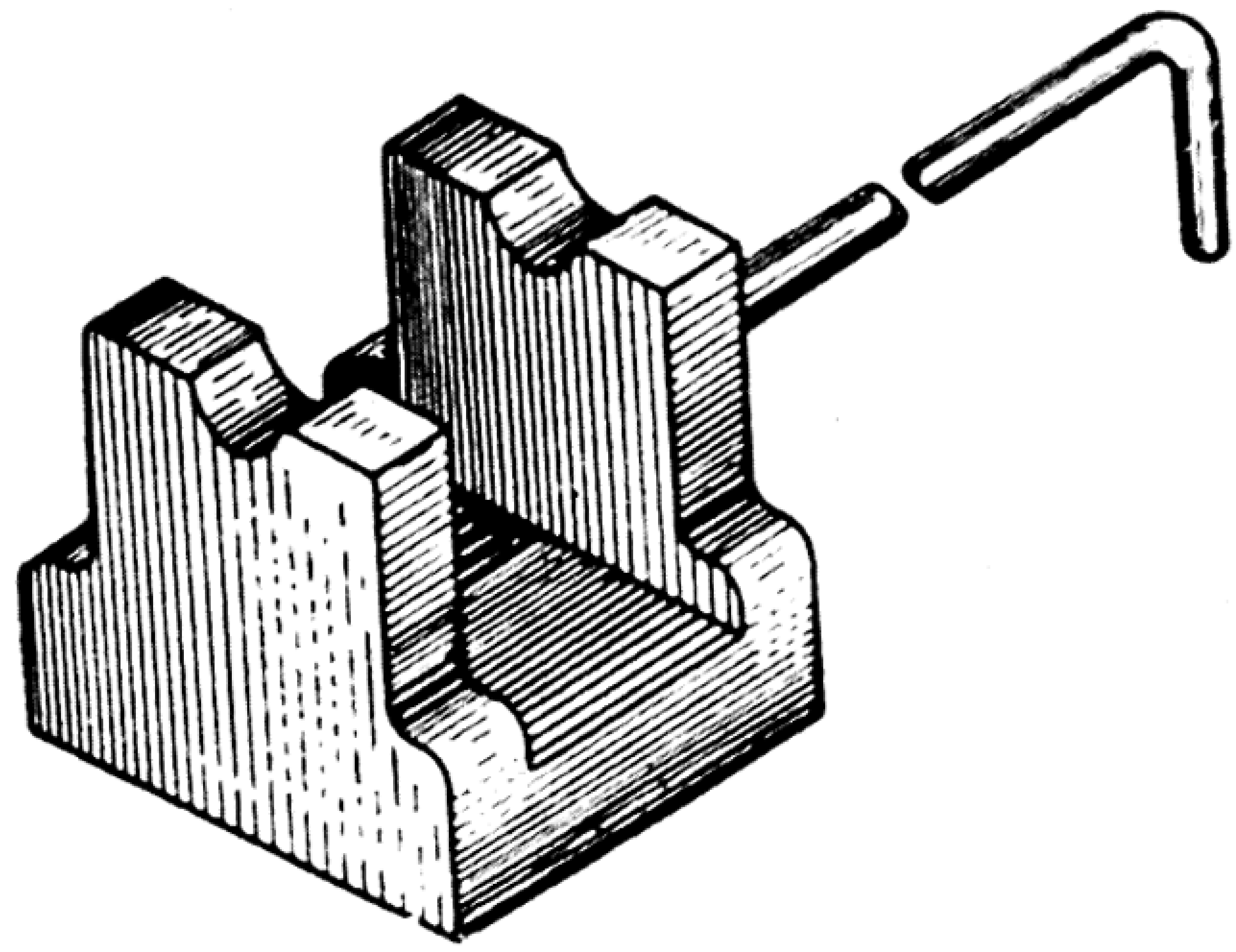


Fig. 203. Saddle for rolling rings up to 400 mm in diameter

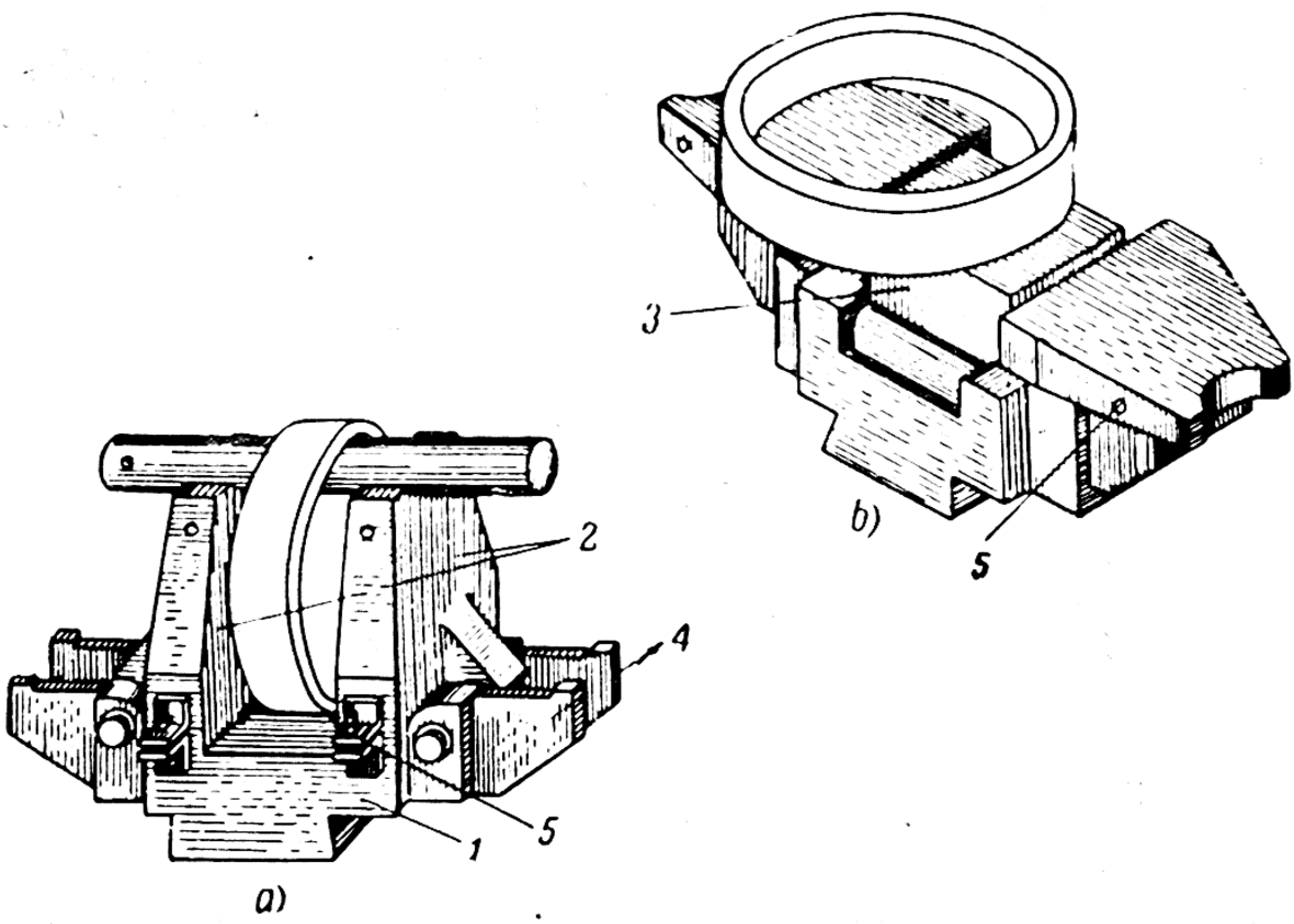


Fig. 204. Ring for rolling fixture

THE PRINCIPAL FORGING OPERATIONS ON FORGE HAMMERS

Hammer forging entails the same operations as those practised in hand forging—cutting, drawing-out, or reducing, upsetting, bending, twisting, punching and piercing holes, and finishing (smoothing) surfaces. The methods used in hammer forging differ but slightly from those used in hand-forging operations.

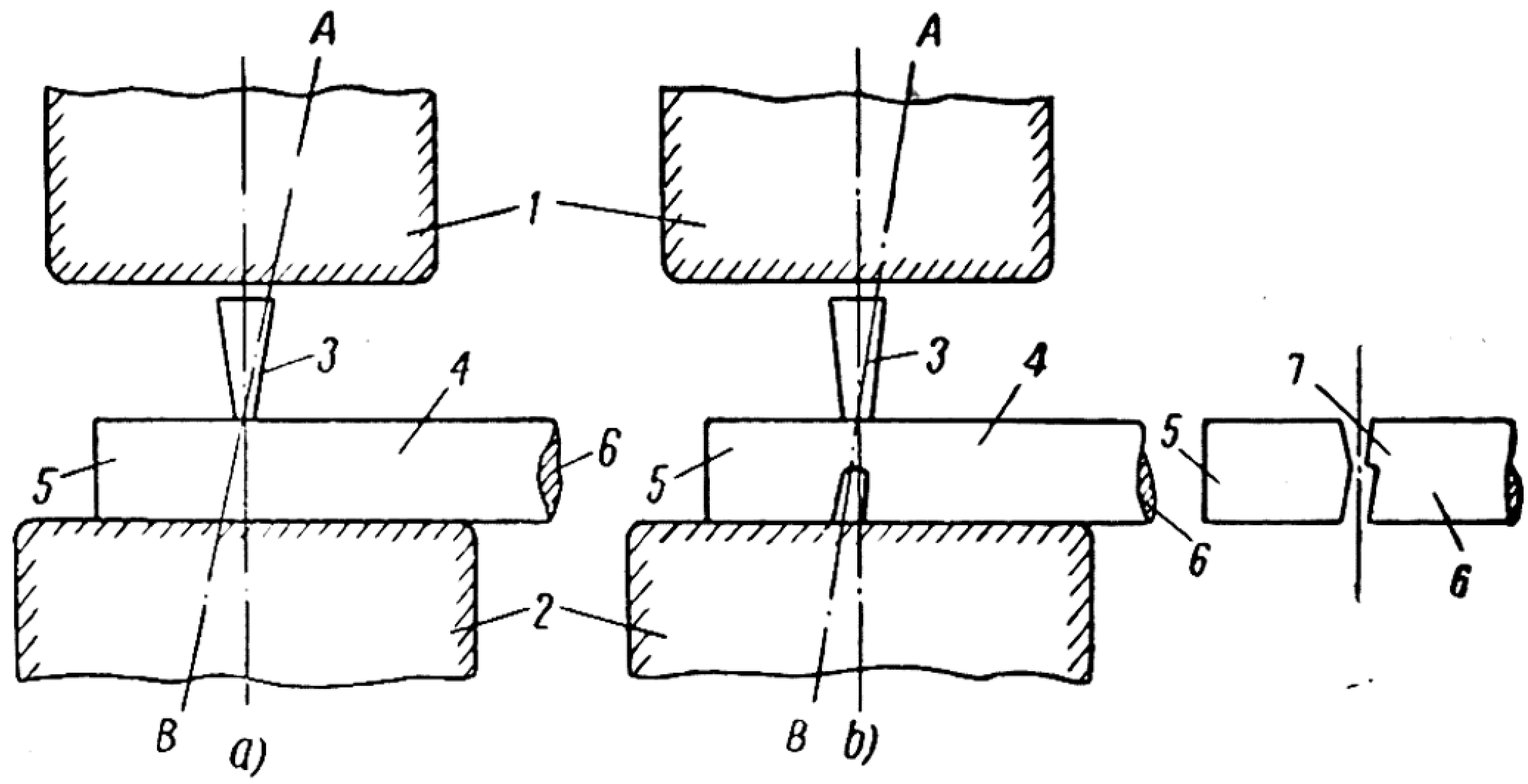


Fig. 205. Cutting a piece of work under a hammer; first method

The following are the principal working methods and rules for using forging tools in executing the main hammer-forging operations.

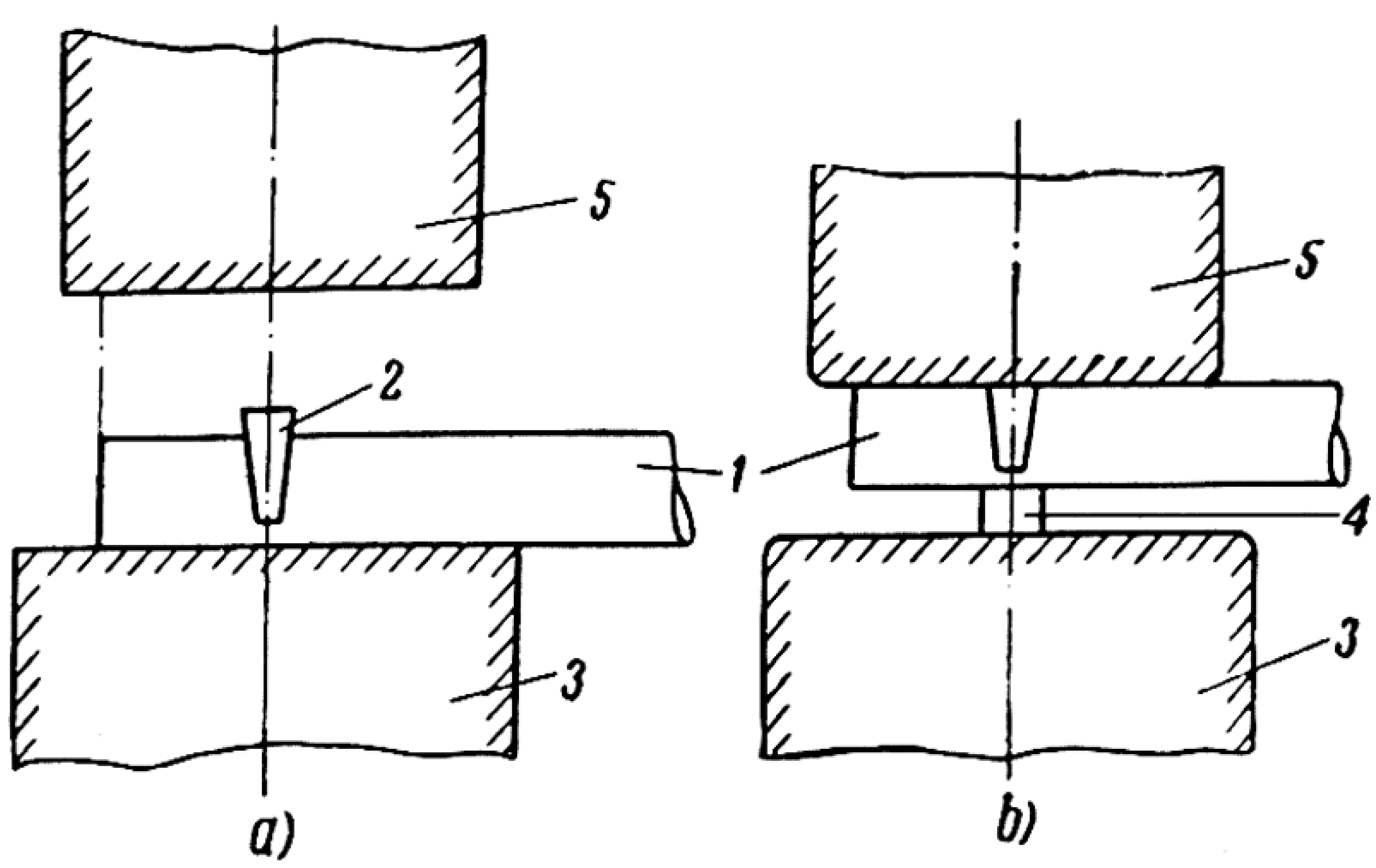


Fig. 206. Cutting a piece of work under a hammer; second method

Cutting. The usual blacksmith's sets are employed for cutting operations in hammer forging. As a rule in hammers the metal should be cut hot at temperatures not below 700°C. Different methods can be employed for cutting stock in hammers; they are as follows:

First method (Fig. 205). The heated stock *4* is placed on the bottom die *2* of the hammer, the location of the cut is marked and hot set *3* placed on this mark. Under the blow of top die *1*, the blade of the hot set will be forced into the metal and will displace it in the direction of least resistance, i. e., in direction *5*, as shown in Fig. 205, *a*. The cutting tool, however, will travel along the line *AB*. After the stock has been notched half way, it must be turned over, the hot set placed opposite the first cut, as shown in Fig. 205, *b*, and the cutting operation completed. Part *5* of the stock will be cut off and the remaining section *6* will have the shape shown in Fig. 205, *c*. When this method of cutting is employed, the stock will have burrs *7* which are then removed with the aid of a square cutter or taper sets.

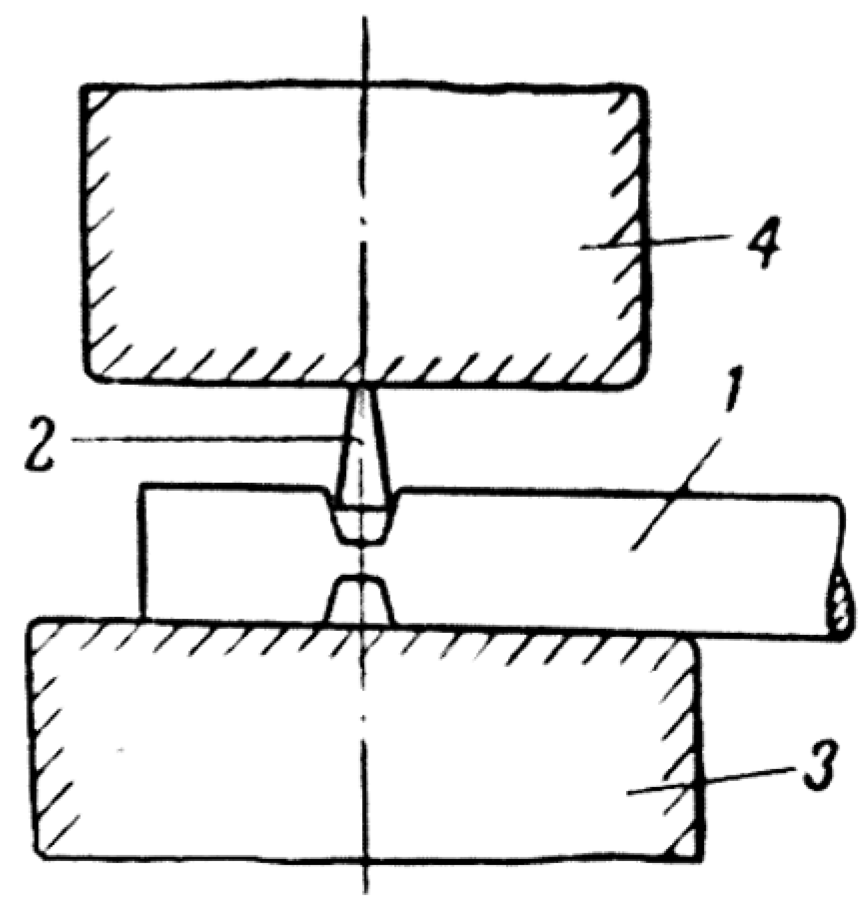


Fig. 207. Cutting a piece of work under a hammer; third method

Second method. Cutting with the aid of a hot set and square cutter, as shown in Fig. 206. Stock *1* is cut nearly all the way, the blade of hot set *2* not being allowed to go completely through the metal, in order to avoid harming bottom die *3* (Fig 206, *a*). The stock must then be slightly lifted and square cutter *4* inserted under the work; the hot set is withdrawn and the work struck by top die *5*, which cuts it in two, as shown in Fig. 206, *b*.

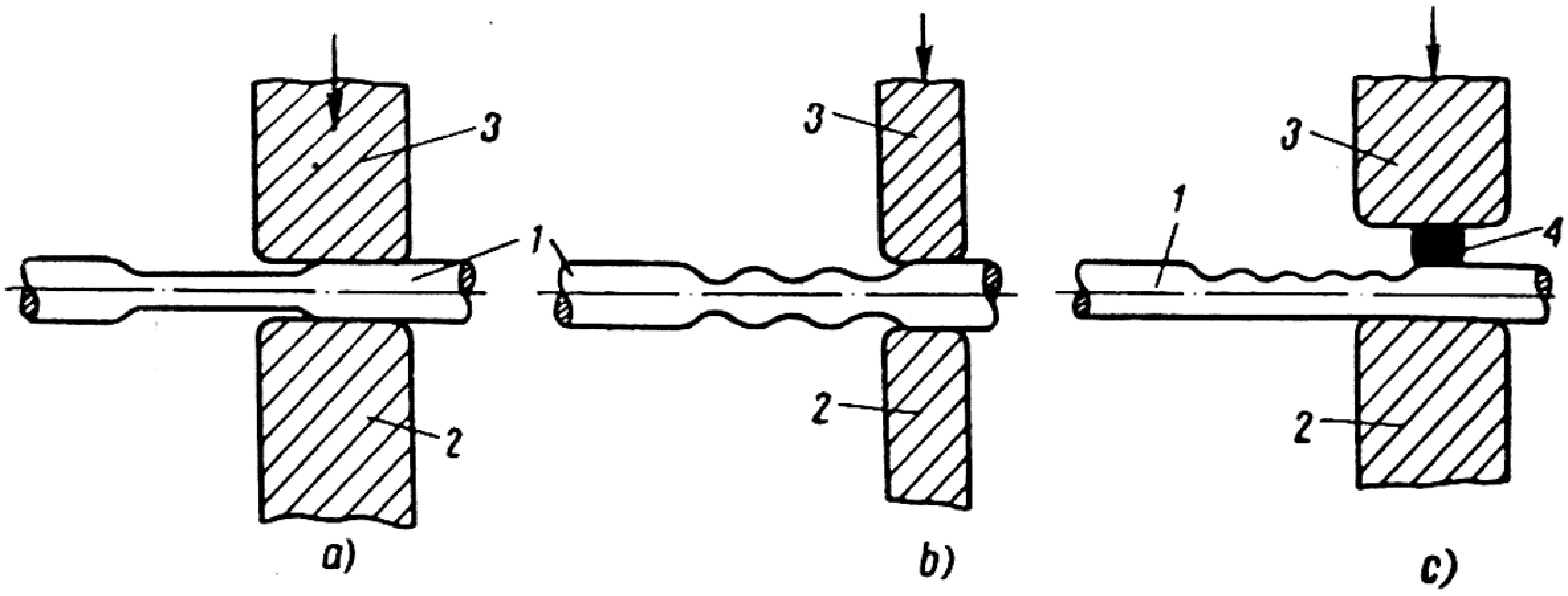


Fig. 208. Various methods of drawing-out

Third method (Fig. 207). Work *1* is placed on bottom die *3* and cut from both sides with hot set *2*, leaving a small neck between the bottom and top cuts. The back of the hot set is then inserted into the cut and its blade struck with top die *4*, thus cutting the narrow neck.

The second method is the safest, and is most generally employed in practice.

Burrs left after the cutting operations must always be removed with the aid of square cutters and taper sets. A piece of work having burrs should never be forged, as they may lead to laps and similar defects.

Drawing-out. Drawing-out is executed between the hammer dies as shown in Fig. 208, *a*. Drawing-out with the edges *3* and *2* of the dies will result in nearly all of the displaced metal being spent for lengthening stock *1*. The same effect is obtained if the operation is carried out with narrow dies, as shown in Fig. 208, *b*, or if a fuller *4* placed between the top and bottom dies is used as shown in Fig. 208,*c*; the fuller in this case will act as a narrow top die, i. e., displace the metal along the length of the stock. Drawing-out between narrow dies is considered the most efficient method. Large forge shops are equipped with hammers with narrow dies for drawing-out, and with wide dies for smoothing, i.e., for finishing the surface of the work after reduction between narrow dies.

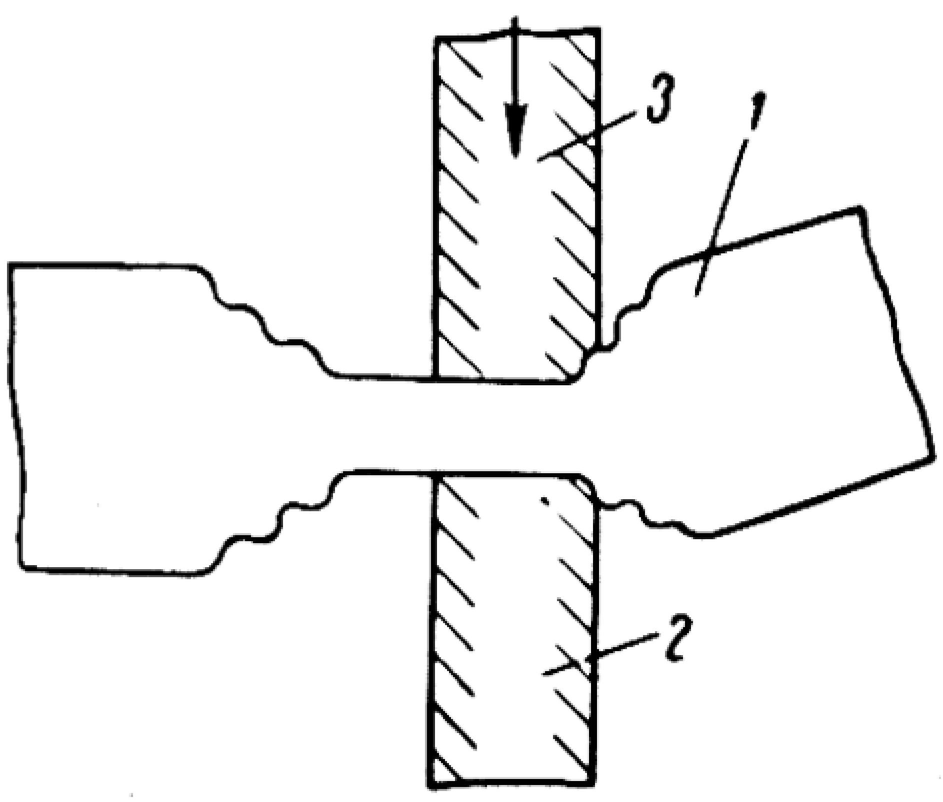


Fig. 209. Bending of stock during drawing-out:
1) stock; 2) bottom die; 3) top die

Drawing-out must be carried out gradually along the entire length of the work, usually beginning from its centre. Short work should be drawn out from one of its ends. Ingots are drawn out from their centre, in order to "squeeze out" the defects located near the ingot head and tail, thereby ensuring that they are discarded together with the top and bottom discards. After one side of the ingot has been struck several times, it must be turned through 90°, hammered, and then returned to its original position and rehammered, the ingot being turned round after every few blows, until it is drawn out (reduced) to the required length and cross-section.

This method of reduction cannot however always be employed. When forging in hammers, the stock will always be cooled by the bottom die more rapidly than by the top one, as the top die contacts the metal only when it strikes it, whereas the bottom die is in contact with the metal all the time it is being forged. This unequal cooling of the work (from its top and bottom) may lead to its distortion—its end may bend up, as shown in Fig. 209. If this occurs, it will be out of the question to turn the forging through an angle of 90°, as it may get out of balance. In such cases the work must be turned over and drawn out on its opposite side, thus straightening it out; after being straightened, it must be once more turned through an angle of 90° and hammered on its edge.

For the complete drawing-out of a piece of work, the metal must be heated to forging temperature throughout its entire length. When

a heavy piece of work is to be completely drawn out, this must be done in sections, each section being heated in turn, i. e., first at one end and, when that has been drawn out, at the opposite end, and so on. When local reduction is required, the work is subjected only to local heating.

Metal must be reduced, or drawn out, by rapid, heavy strokes. when the penetration of the force of the blow will be deeper, and the grain of the metal will be refined throughout its entire cross-section. Light blows, on the contrary, only result in the deformation of the surface of the metal, and in drawing-out its core to a much smaller degree; as a result, stresses will develop between the inner and outer layers of the metal, which may lead to cracks.

Drawing-out should be conducted between flat top and bottom dies, or between a flat top die and a recessed bottom die. Round work can be reduced much more rapidly between recessed dies than between flat dies; when hammered between recessed dies, the transverse flow of the metal will be less than when hammered between flat dies. Work can be drawn out from 20 to 30 per cent faster between recessed top and bottom dies than between flat top and bottom dies; and drawing-out between a flat top die and a recessed bottom die, though faster than drawing-out between flat top and bottom dies, is nevertheless slower than between recessed top and bottom dies.

Upsetting. Upsetting is an operation whereby the cross-sectional area of a forging is increased and its height reduced. Upsetting is accompanied by considerable stresses resulting from the strains developed in the metal. Before being upset, the work must be heated throughout its entire cross-section and along its entire length to a high temperature.

Upsetting is resorted to in the following cases: 1) when the fibre of the metal has to be given a definite direction to ensure higher strength of the forging (as, for instance, when forging gear blanks); 2) when forging a stock of required weight but of insufficient cross-section; 3) when the available stock does not ensure the required reduction factor.

When upsetting, care must always be taken that the length of the stock does not exceed 2.5 times its diameter or thickness. Otherwise the stock may buckle and even fly out of the dies during the upsetting process.

Before being upset, the work must be heated uniformly throughout its entire mass and then placed vertically in the centre of the bottom die. Then, under repeated blows of the top die, its cross-section is increased and its height reduced (Fig. 210). During this operation. the stock must be turned round its vertical axis after each blow. To speed up the upsetting process, half-round or oval fullers are sometimes employed; and, towards the completion of the process, a steel

bar 3-4 mm thick and 70-80 mm wide is used after which the forging is smoothed out between flat top and bottom dies.

The head or central section of short pieces of work is usually upset in rings. Fig. 211 illustrates one method of upsetting the head of a piece of work in an upsetting ring. Ring *3* is placed on bottom die *4*; the diameter of its hole must be slightly larger than that of stock *1*, and the height of the ring must be equal to that of the section of the stock which is not to be upset. After being heated to the required temperature, the stock is inserted in the ring, and its projecting head *1* struck by top die *5*, thus upsetting it to the shape shown in Fig. 211, *2*.

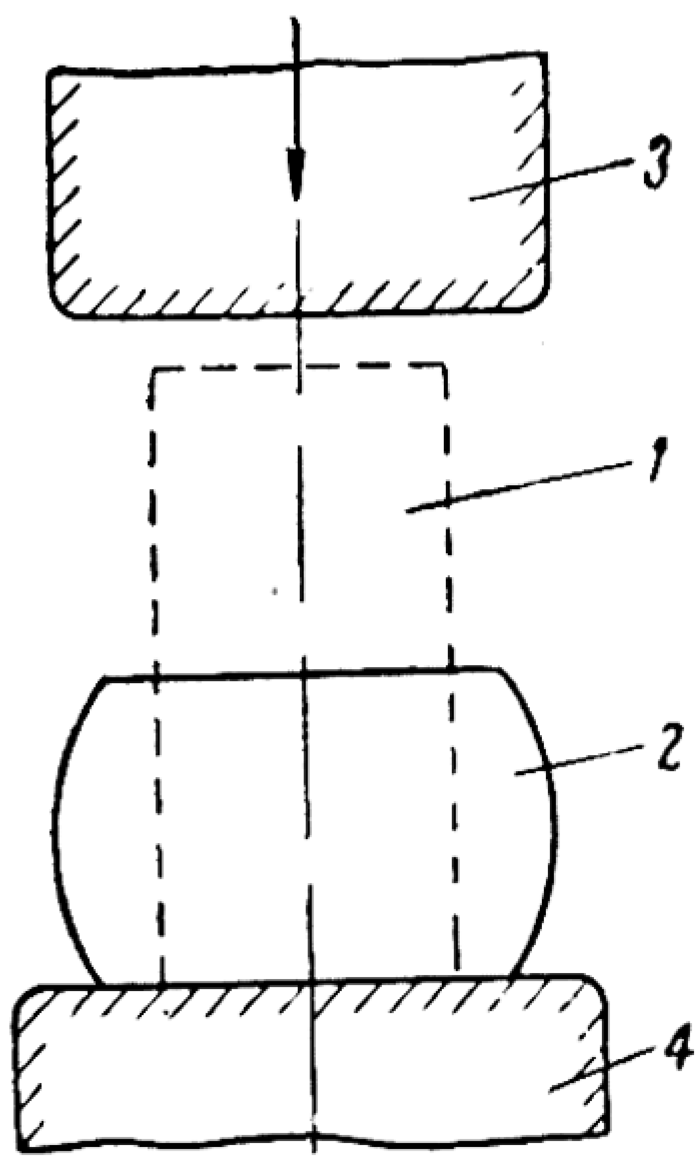


Fig. 210. Upsetting:
1) stock before upsetting;
2) stock after being upset;
3) top die; 4) bottom die

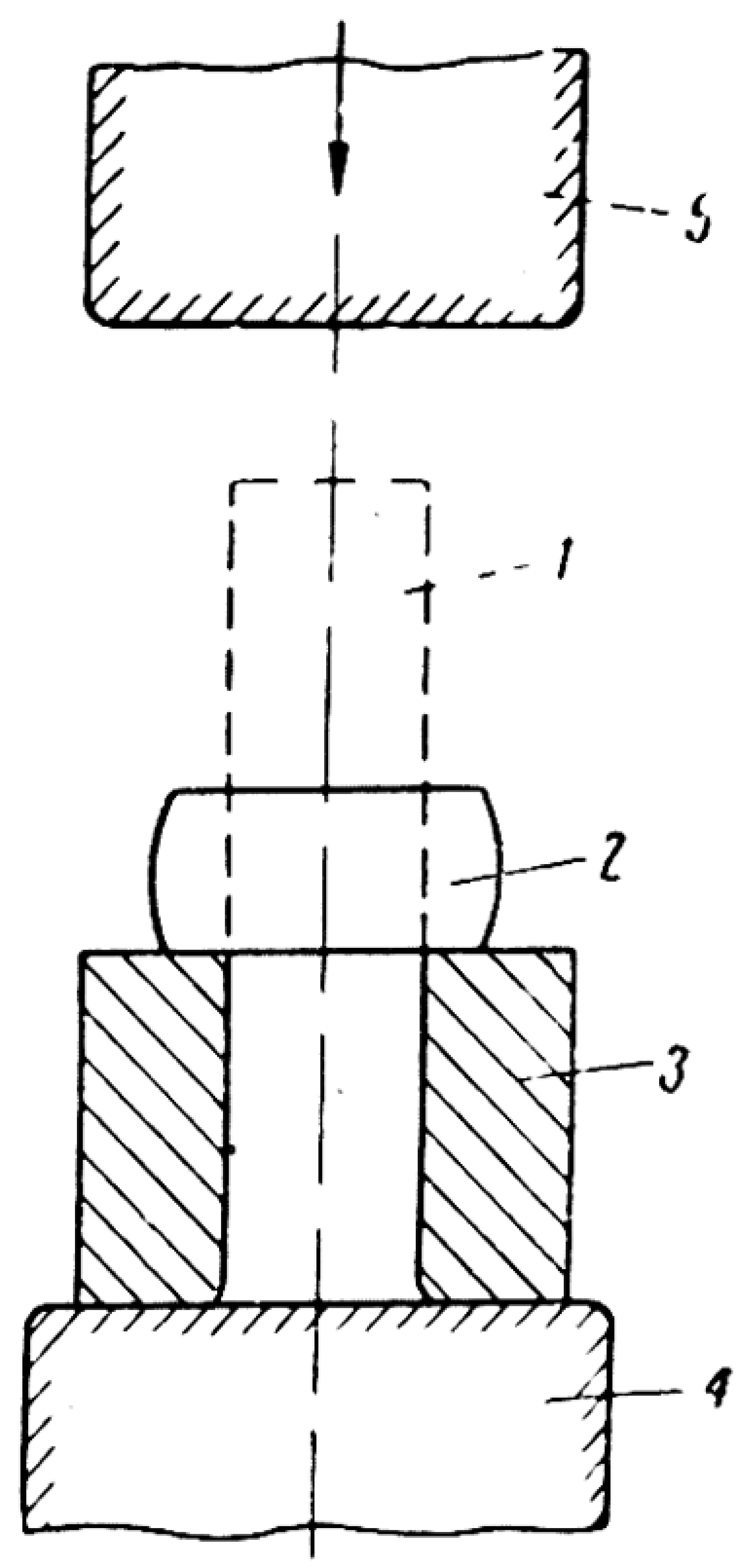


Fig. 211. Upsetting the end of a piece of stock in an upsetting ring

To facilitate the removal of the section of the forging which has not been upset from the ring, the inside diameters of upsetting rings have a taper of 6-7°; they are, however, also made without tapers, in which case the forging is removed with the aid of inserts and extension rings as shown in Fig. 212. In order to remove the forging from upsetting rings by this method, upsetting ring *3* is slightly raised and insert *4* placed between the ring and bottom die *5*. The diameter of this insert must be less than that of the ring; extension ring *1* is then placed on upsetting ring *3*; when top die *6* strikes ring *1*, the head of the forging will be driven out of upsetting ring *3*.

The centre of short work can likewise be upset with these rings, as shown in Fig. 213. In this case both ends of the stock are first drawn out to the required diameter *1*; one end is then inserted in bot-

tom ring *3* placed on bottom die *6*, and upper upsetting ring *4* is placed over the opposite end. Stock *2* is then struck by top die *5* through ring *4* until the central portion of the stock has been upset to the required dimensions.

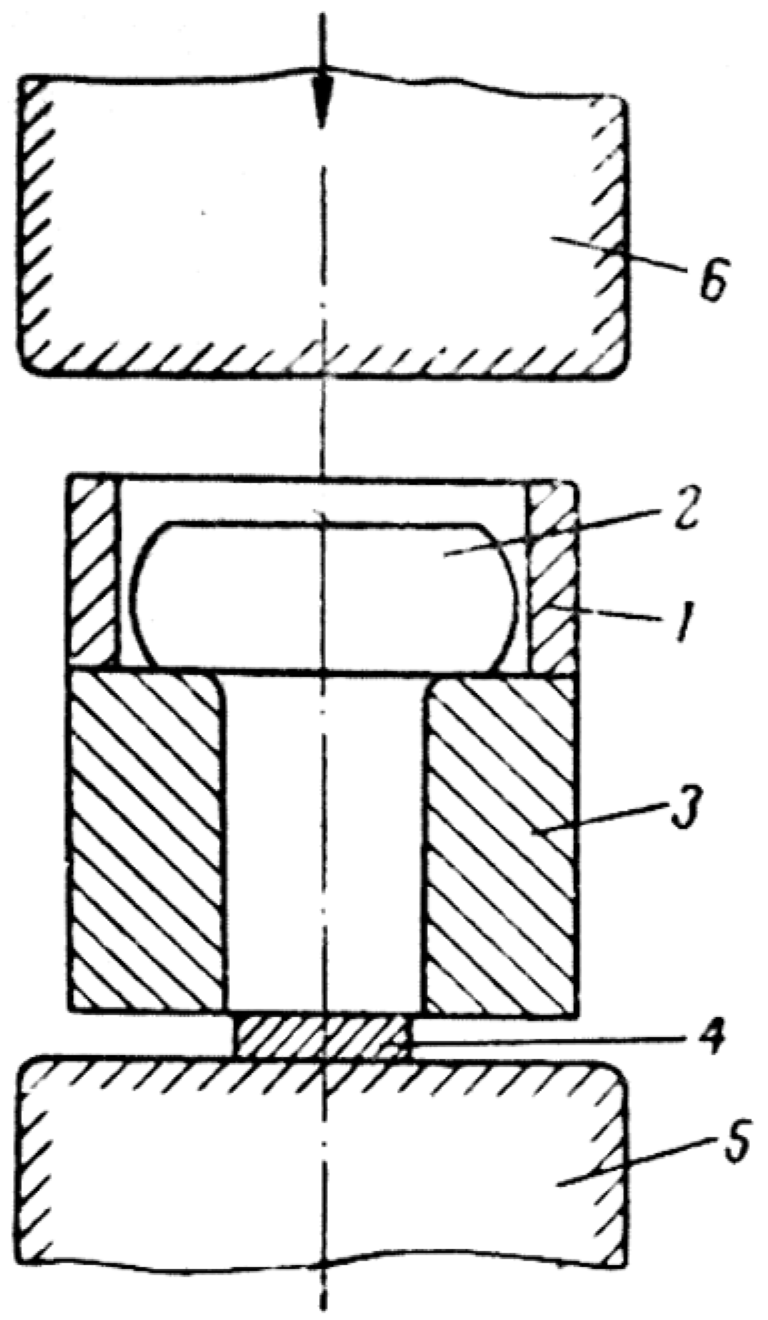


Fig. 212. Removing the upset forging from the ring

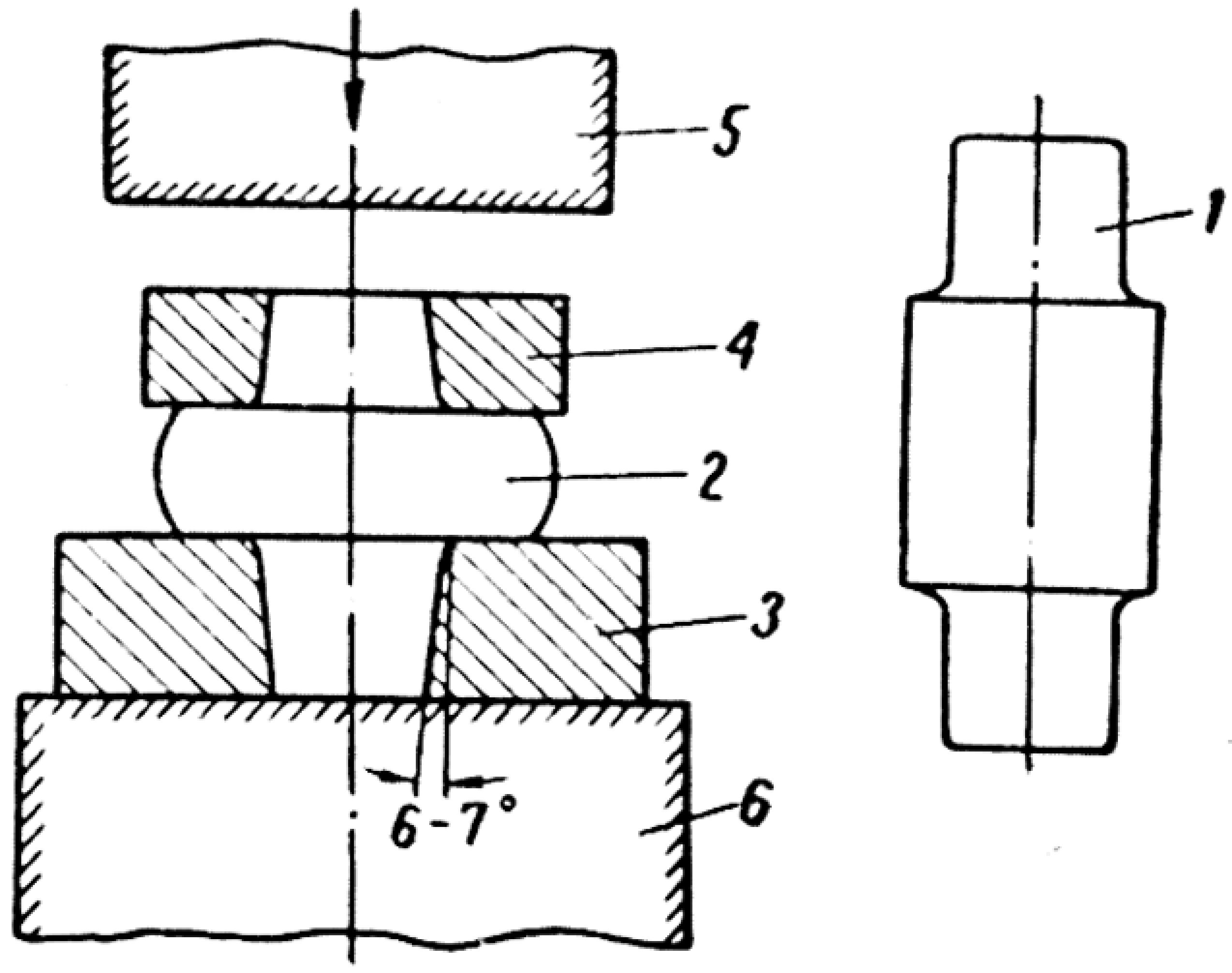


Fig. 213. Upsetting (jumping) a piece of work at its centre with the aid of upsetting rings

When upsetting the central section of a piece of work by this method, the inside diameter of one of the upsetting rings must have a

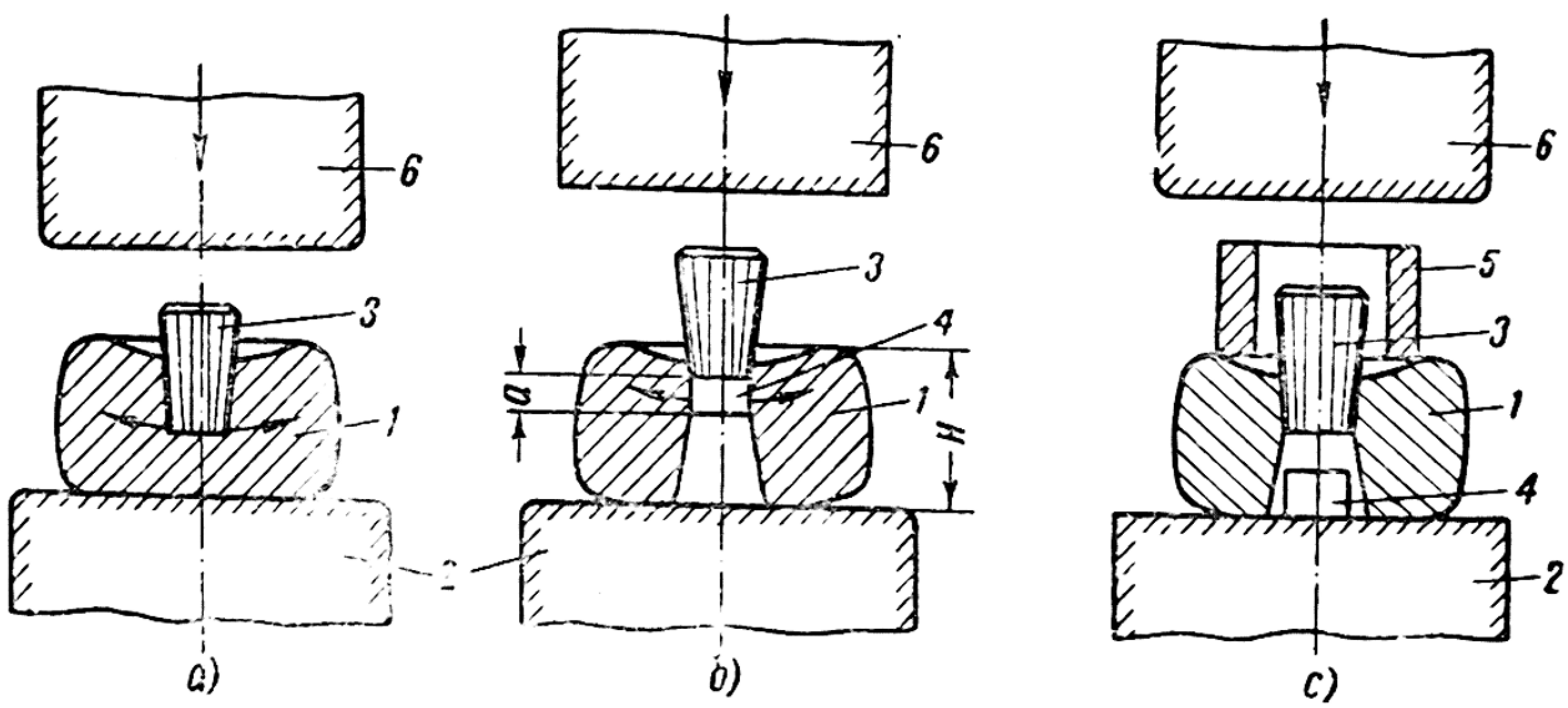


Fig. 214. Schematic illustration of punching a hole:
a) the first operation; b) the second operation; c) removing punch; 1) stock; 2) bottom die; 3) punch; 4) slug; 5) ring; 6) top die

taper of 6-7°, as otherwise the work will be very difficult to withdraw.

Punching and Piercing Holes. Holes in thick billets are made with special punches, the use of which differs from that employed in hand

punching or piercing. Fig. 214 shows how a hole is punched in a thick piece of work. Here, stock *1* is placed on bottom die *2* of the hammer, without using any bolster dies or rings. Punch *3* is then placed on the stock and forced into the metal by blows of the top die, as shown in Fig. 214, *a*. As the stock is in close contact with the surface of the bottom die, the metal will be forced to flow transversely away from the punch, thereby increasing the diameter of the stock (the stock "spreads"), and also leading to its distortion (the stock bends upwards, as can be seen from Fig. 214, *b*). The stock is then turned over, through an angle of 180°. The opposite surface of the work will display a slightly darkened area corresponding to the outline of the base of the punch, which must be placed exactly over it; the punch is then driven into the work by the blows of the top die, as illustrated by Fig. 214, *b*. When the hole is finally punched from this side, slug *4* will fall away.

The punch is prevented from sticking in the metal at the beginning of the punching operation as follows: after ascertaining that the punch has been correctly installed, it is struck lightly by top die *6*, and then withdrawn from the impression it has made when powdered charcoal is sprinkled inside the hole. The heat generated by the subsequent blows of the die against the punch, will ignite the charcoal, which will burn away; the resultant gases will attempt to force the punch out of the hole in the stock, thereby facilitating its removal from the hole after punching. Fig. 214, *c* illustrates another method of withdrawing punches with the aid of a ring. By this method ring *5* is placed over the punch and onto the stock; the ring is then struck lightly by top die *6*, whereupon the stock will straighten out and the punch can be easily withdrawn.

The hole thus formed will not be of proper shape, as the punch itself is tapered. For this reason, the hole must be finished, or sized, to the required dimensions and shape with tapered or barrel-shaped mandrels in the manner shown in Fig. 215.

In addition to the above methods of punching holes, they can also be pierced in the way shown in Fig. 216. Here the work is placed over ring *2* the inside diameter of which is slightly larger than that of the hole to be punched; the hole is made with the larger end of punch *3*. The hole is then punched right through the metal without turning the work over. Slug *4* falls out through the hole of the inserted ring. During piercing, the dimensions and shape of the work remain practically unchanged while during punching both dimensions and shape are altered. This circumstance is a deciding factor in the choice of the method used for making holes. Usually the following rule is observed: if the work has been completely forged and only a hole remains to be made in it, it is pierced; holes are punched if they are to be bored after the forging is completed.

The height of the slug a (see Fig. 214, b) when holes are punched usually equals one-third of the height H of the work. The volume V of the slug in this case will be equal to the area A of the base of the punch, multiplied by one-third of the height of the work:

$$V_{sl}=\frac{AH}{3}$$

The height of the slug of a pierced hole is accepted as being 0.9 of the height of the pierced work: $a=0.9\ H$.

Bending. Frequently a forging has to be bent at various angles. To do this, the work, when forged in hammers, must be held between the top and bottom dies and bent to the required angle by striking its free end with a sledge-hammer. In this case, the outer layers of the metal will be stretched and its inner layers compressed. Before bending, the work must be subjected to local heating, i. e., it must be heated only at the place where it is to be bent.

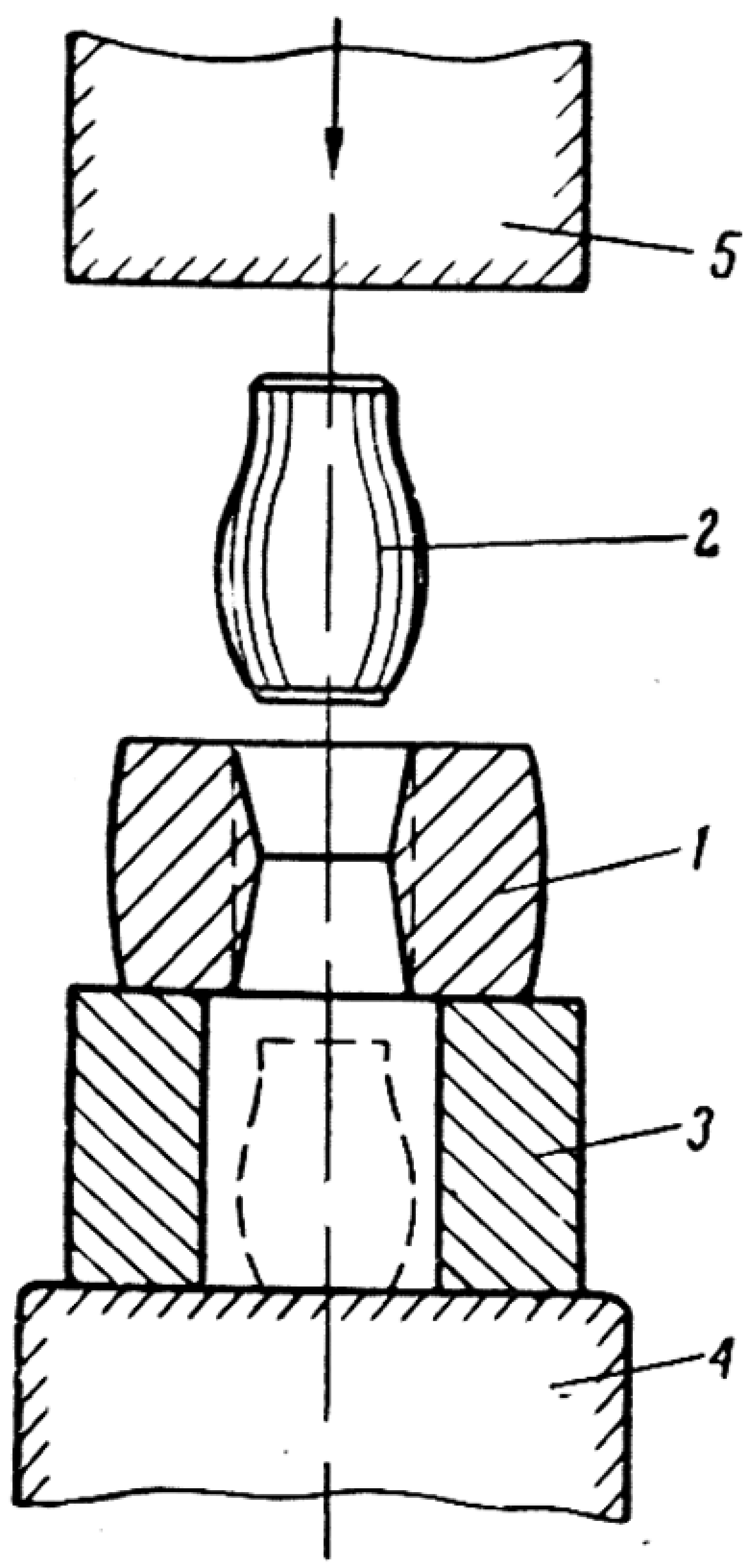


Fig. 215. Sizing a hole:
1) stock; 2) sizing punch; 3) ring; 4) bottom die; 5) top die

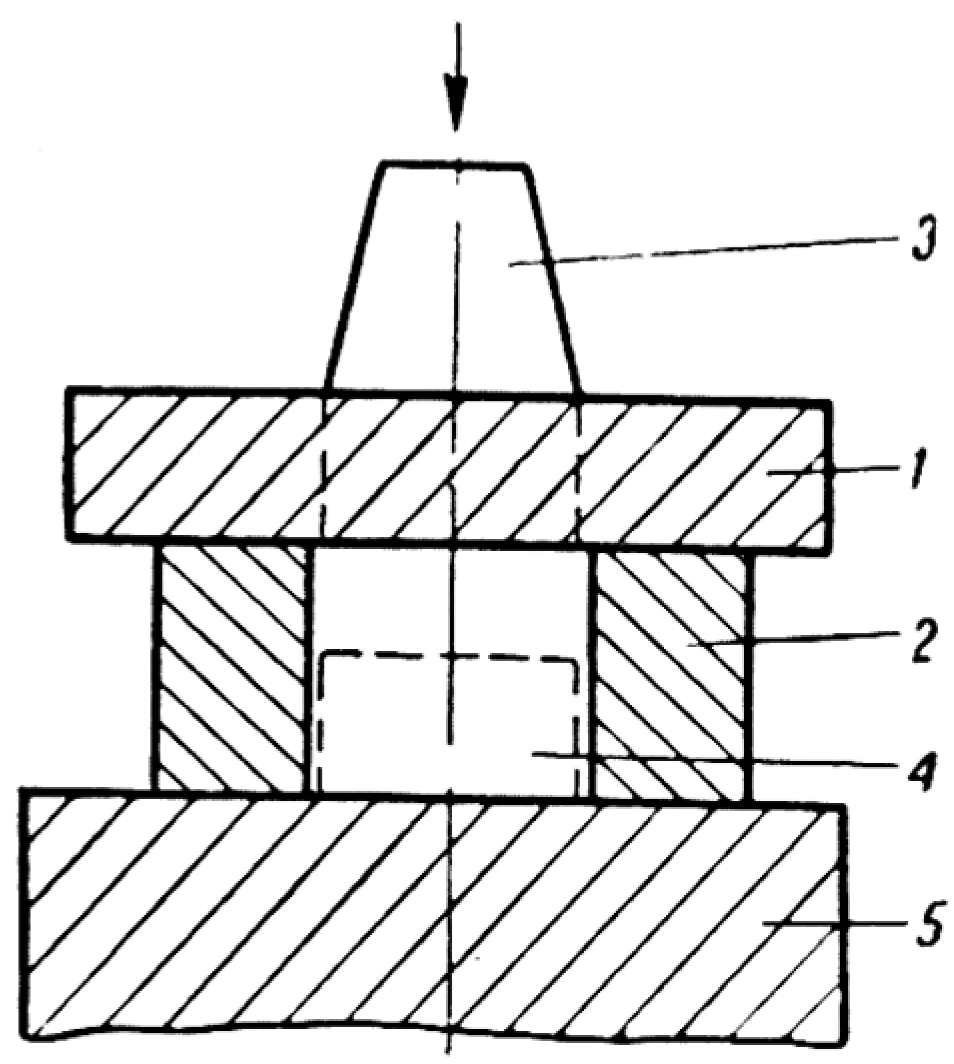


Fig. 216. Piercing a hole:
1) stock; 2) ring; 3) punch; 4) slug; 5) bottom die

Whenever possible, insert dies should be employed for bending in hammers. Bending in insert dies is much more rapid, and the dimensions of the forging are more accurate. Insert dies are used when a considerable quantity of duplicate forgings have to be made, in order to justify the expense of making the insert die.

Surface Finishing. The surfaces of forgings must always be finished by smoothing; they are smoothed with flatters, or smoothers, as they are also called, of various designs depending on the shape of

the surface of the forgings. Flat forgings are sometimes smoothed with light blows of the flat top die. This is always the last forging operation, which is performed after the scale has been removed. Should it be required to reheat the forging for smoothing, the scale formed by this must always be first brushed off.

Since *smoothing*, as has already been said, is the final forging operation, it is always accompanied by the checking of the dimensions of the forging against the drawing. If the forging is of a complicated and assymetrical shape, it must be checked by placing a template against the surface; this will clearly show whether the forging has been made properly, and where it has to be corrected.

Insert Dies. Of recent years the insert dies have been increasingly widely employed in hammer forging. Their use does not entail any large expense, and therefore their manufacture is justified even when forging small lots of duplicate work. The chief advantage of insert dies is that they limit the flow of metal to the walls of their impression and that the precision of the resulting forgings approaches that of die forgings. This permits a considerable reduction in machining allowances and, consequently, in the consumption of metal and the total man-hours required for the production of forgings. Moreover, the working conditions of the blacksmiths are improved, and their productivity is increased from 5 to 6 times.

Technological process Chart 5 for forging a bevel-gear blank, given in Chapter XVII, illustrates an example of hammer forging in insert dies. This is a flange-type forging made in an insert ring.

CHAPTER X

THE TECHNOLOGICAL PROCESS AND EXAMPLES OF HAMMER FORGING

THE TECHNOLOGICAL PROCESS

One and the same component can be forged by different methods and on different forging machines. However, it is always necessary to select the most suitable method for making any given forging, which will: a) ensure a high-quality forging; b) ensure high productivity, i. e., entail the least expense of time in making the forging; c) entail the minimum consumption of physical energy on the part of the workers; d) entail the minimum consumption of metal; and e) ensure complete safety during forging.

The process of making a part by forging consists of several separate *operations*, the chief of which are: 1) selecting and preparing the stock for forging; 2) heating the metal for forging; 3) forging the stock to the requisite shape and dimensions. The process of making any piece of work by the hammer forging method entails many different forging operations—cutting, upsetting, bending, drawing, piercing, punching, drifting, twisting and surface finishing. The production of any kind of forging necessitates the employment of some, or all of these operations in different sequences. Sometimes, one, two or three operations (steps) may have to be repeated several times.

Every blacksmith should always try to make his forgings in the least possible number of operations. This will reduce the time needed for making the forging, reduce the number of heatings and, consequently, increase his productivity. Before commencing to make any forging, the blacksmith should know exactly which operations are to be employed, and in what sequence. The tools and devices which he selects will depend on the method of forging.

The blacksmith generally works together with one or more strikers; and, to ensure perfect co-ordination between him and his strikers, he must explain the sequence of each operation and tell them beforehand which tools they will have to use. The striker, under the blacksmith's supervision, has to put each tool in its working place in the order of the operations to be performed; this prevents any delays entailed in looking for the required tools during the work.

The basic document for making any hammer forging is what is called the technological process chart, which sets out the sequence

of each forging operation. Process charts *specify*: 1) the grade of steel required for a given forging; 2) the dimensions and weight of the stock for the forging; 3) the tools and equipment required for making the forging, including furnaces, cranes, hammers, etc.; 4) how many pieces of stock are to be charged into the furnace at one heat, and the method of stacking the stock in the furnace; 5) the time required for heating the steel to the forging temperature; 6) the initial forging temperature of the steel; 7) the final forging temperature of the steel; 8) composition of the crew employed in making the forging; 9) the time required for making the forging; 10) the scheme of organisation of the working place; 11) operations and passes, tools and devices, required for making the forging. Moreover, every process chart gives a forging drawing of the work.

Below a few examples of hammer forging are described.

EXAMPLES OF HAMMER FORGING

Forging a Shaft. Required: to draft a process chart for making the forging of the stepped shaft, shown in Fig. 217. Material—grade 45 steel.

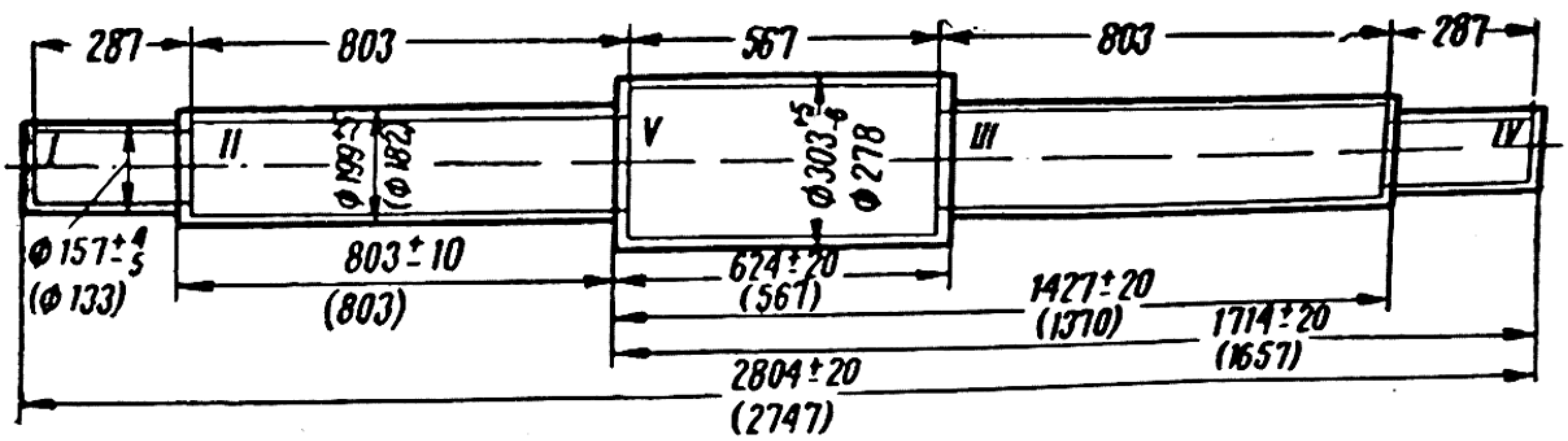


Fig. 217. Drawing of a stepped shaft forging

The first stage in drafting the process chart is to make a forging drawing. Let us consider all the stages of drafting the technological process in detail.

1. *Making the forging drawing of the shaft.* For this, the outline of the shaft is drawn, in thin lines, and its chief finished dimensions written in. Then the machining allowances and forging tolerances are specified, taking them from GOST 7829-55.

From Appendices 2 and 3, the basic allowances and tolerances are selected for the diameter of each step, for the total length and for the length of each section of the shaft; from Appendix 4 the additional allowances for the diameters of each section are calculated. The basic allowances and tolerances for the diameters of each section for a shaft with a total length of 2,747 mm will be the following:

For diameters:

$$\begin{aligned}
D_1 &= 133 \text{ mm} & a_1 &= 16^{+4}_{-5} \text{ mm}\\
D_2 &= 182 \text{ mm} & a_2 &= 17 \pm 5 \text{ mm}\\
D_0 &= 278 \text{ mm} & a_0 &= 19^{+5}_{-6} \text{ mm}\\
D_3 &= 182 \text{ mm} & a_3 &= 17 \pm 5 \text{ mm}\\
D_4 &= 133 \text{ mm} & a_4 &= 16^{+4}_{-5} \text{ mm.}
\end{aligned}$$

Additional allowances for the diameters of each section: on section with $D_1=133$ mm, for difference $D_0-D_1=145$ mm, the additional allowance S_1 will be 8 mm. This allowance is specified for the section having a diameter D_1, since the ratio $\frac{l_1}{l_0}=\frac{287}{567}=0.5$, which is less than 2, indicated in *Appendix* 4 for sections of this diameter.

For section with $D_2=182$ mm, S_2 will be 6 mm. This allowance is specified for the section with $D_0=278$ mm, inasmuch as ratio $\frac{l_2}{l_0}=\frac{803}{367}=$ $=2.2$, which is more than the ratio 1.5 for the diameter of this section.

For section with $D_3=182$ mm, S_3 will be 6 mm.

For section with $D_4=133$ mm, S_4 will be 8 mm. Consequently, the diameters of the various sections of the shaft, including their allowances and tolerances, will be as follows:

$$\begin{aligned}
D'_1 &= 133+16^{+4}_{-5}+8=157^{+4}_{-5} \text{ mm}\\
D'_2 &= 182+17\pm5=199\pm5 \text{ mm}\\
D'_0 &= 278+19^{+5}_{-6}+6=303^{+5}_{-6} \text{ mm}\\
D'_3 &= 182+17\pm5=199\pm5 \text{ mm}\\
D'_4 &= 133+16^{+4}_{-5}+8=157^{+4}_{-5} \text{ mm.}
\end{aligned}$$

The allowances and tolerances for the length of each section will be calculated from the initial base for the section with diameter $D_0=$ $=278$ mm and for the total length $L=2{,}747$ mm of the shaft. They will be the same for each section. According to *Appendices* 2 and 3, the allowance and tolerance b for the length will be equal to 57 ± 20 mm or $\frac{b}{2}$ per side.

The total length of the forging and the lengths of each section will be:

Total length $L'=2{,}747+57\pm20=2{,}804\pm20$ mm.

Length of section V:

$$l'_0=567+57\pm20=624\pm20 \text{ mm.}$$

Length of section II

$l_2' = (803 - \frac{57}{2}) + \frac{57 \pm 20}{2} = 803 \pm 10$ mm.

Length of section III

$l_3' = (803 - \frac{57}{2}) + \frac{57 \pm 20}{2} = 803 \pm 10$ mm.

Length of section IV

$l_4' = (287 - \frac{57}{2}) + \frac{57 \pm 20}{2} = 287 \pm 10$ mm.

After the above calculations have been made, we ascertain the possibility of forging the sections using *Appendix* 5.

The length l_2' of section II is 803 mm. The diameter of the adjacent section D_0' is 303 mm. Consequently, section II located between them will be forged without any additional allowance, as its length is greater than the corresponding length indicated in the table. The length l_1' of section I is 287 mm. The diameter of the adjacent section D'_2 is 199 mm. According to the table, this section can be forged without any additional allowances since its length is greater than the corresponding length indicated in the table.

Sections III and IV are of the same length and diameter as sections I and II, and are therefore to be forged with the same allowances and tolerances.

After the allowances and tolerances for each section of the shaft have been calculated, its forging drawing is made. The forging contour of the shaft is drawn in thick lines around the thin-lined drawing, and the forging dimensions, calculated from the allowances and tolerances just found, written in. The thick-lined contour of the drawing shown in Fig. 217 represents the forging drawing of our shaft.

2. *Determining the volume and weight of the forging.* For this purpose, the shaft is divided into five sections, I, II, III, IV and V. In this case, sections I and IV, and II and III have the same dimensions nd, consequently, their volumes will be equal.

The volume of section I and, consequently, of section IV will be:

$$V_{1-4} = \frac{\pi (D_1')^2}{4} l_1' = \frac{3.14 \times 15.7^2}{4} \times 28.7 = 5{,}556 \text{ cm}^3.$$

The volume of section II and, consequently, of section III:

$$V_{2-3} = \frac{\pi (D_2')^2}{4} l_2' = \frac{3.14 \times 19.9^2}{4} \times 80.3 = 24{,}973 \text{ cm}^3.$$

The volume of section V, will be:

$$V_5 = \frac{\pi (D_0')^2}{4} l_0' = \frac{3.14 \times 30.3^2}{4} \times 62.4 = 44{,}997 \text{ cm}^3.$$

The volume of the entire forging will be:

$$V_{forg}=V_1+V_2+V_3+V_4+V_5 \text{ cm}^3.$$

By substitution, we obtain:

$$V_{forg}=5{,}556+24{,}973+24{,}973+5{,}556+44{,}997=106{,}055 \text{ cm}^3.$$

The weight of the forging of the shaft will be:

$$W_{forg}=V_{forg}\,g=\frac{106{,}055\times 7.85}{1{,}000}=833 \text{ kg}.$$

3. *Calculating the volume and weight and selecting the dimensions of the stock.* It is taken that the shaft is to be forged from a billet of square section. The volume of the stock (billet) will then be:

$$V_{stock}=V_{forg}+V_{crop}+V_{sc} \text{ cm}^3.$$

Calculating the volume of the cropping from each end of the stock from the formula: $V_{crop}=0.23d^3\text{cm}^3$, where d is the diameter of the cropped ends, which in this case equals $D_1'=d=157$ mm, the result is obtained: $V_{crop}=0.23\times 15.7^3=0.23\times 3{,}869.9=889$ cm³ per end; for both ends, the corresponding volume will be $889\times 2=1{,}778$ cm³.

The volume of the forging, together with its croppings will be:

$$106{,}055+1{,}778=107{,}833 \text{ cm}^3.$$

It is ascertained that the forging will require two heatings; taking the volume of loss due to scale as being 3.5 per cent of the weight or volume of the forging together with its cropping, it is found that: $V_{sc}=107{,}833\times 0.035=3{,}774$ cm³.

The total volume of the required stock will therefore be:

$$V_{forg}=106{,}055+1{,}778+3{,}774=111{,}607 \text{ cm}^3,$$

and its weight will be:

$$W_{forg}=\frac{111{,}607\times 7.85}{1{,}000}=876 \text{ kg}.$$

The *cross-sectional area of the stock must now be calculated*:

a) since the forging is to be made from rolled steel, its reduction factor is taken as being 1.4;

b) the maximum diameter of the forging (Fig. 217, section V) $D_0=303$ mm; its cross-sectional area will be:

$$A_{forg}=\frac{3.14\times 30.3^2}{4}=721 \text{ cm}^2;$$

c) the cross-sectional area of the billet must be not less than:

$$A_{stock}=721\times 1.4=1{,}009.8 \text{ cm}^2.$$

Such a cross-sectional area will correspond to a square billet 319×319 mm. Billets of this size are not available. The square billet which most nearly approximates the one required is taken—$320\times\times 320$ mm, with a cross-sectional area of 1,024 cm².

The length of the billet which will be used as stock is now calculated by the following formula:

$$L_{stock}=\frac{V_{stock}}{A_{stock}}=\frac{111,607}{1,024}=108.9 \text{ cm.}$$

For making the shaft, a billet of the following dimensions is selected: length—1,090 mm; cross-section—320×320 mm.

4. *Determining the passes needed for forging the shaft and calculating its intermediate dimensions* (Fig. 218).

The first step, or pass, in making the forging will be the cutting of the stock to a length of 1,090 mm (Fig. 218, *a*). The second pass will be the drawing, or reducing, of the stock to a diameter of 315 mm, as, when the stock is grooved, the metal at the corners of section V will unavoidably spread out.

The distance between the ends of the stock and the grooves for section V must now be calculated; the cross-sectional area of the stock with diameter $D=315$ mm will be:

$$A_{stock}=\frac{3.14\times 31.5^2}{4}=779.3 \text{ cm}^2.$$

The third pass will be the grooving of section V (Fig. 218, *b*).

The volume of metal required for sections I and II and for the croppings will be: 5,556+24,973+889=31,418 cm³.

The distance between the grooves will be:

$$\frac{31,418}{779.3}=40.3 \text{ cm.}$$

On section V, the distance between the grooves will be:

$$\frac{V_5}{A_{stock}}=\frac{44,997}{779.3}=57.7 \text{ cm.}$$

The fourth pass will be the reducing (drawing) of the end of the shaft (sections I+II) to diameter $D'_2=199$ mm, and grooving section I (Fig. 218, *c*). The fifth pass (Fig. 218, *d*) will be the reducing of section I to diameter $D'_1=157$ mm; cropping the end; straightening and finishing the surface of forged sections I and II. Then, in the same sequence, sections III and IV are forged, after which the forging of section V to the required dimensions is completed (Fig. 218, *e*).

The tools and devices necessary for executing the above-mentioned operations are likewise indicated on the process chart.

5. *Selecting a suitable hammer for forging the shaft* shown in Fig. 217. From Table 7 it is found that a forging having a maximum diameter of 303 mm and weighing 833 kg can be forged on a hammer with falling parts weighing 5,000 kg. The required forging temperature interval will be 1,220-700° C.

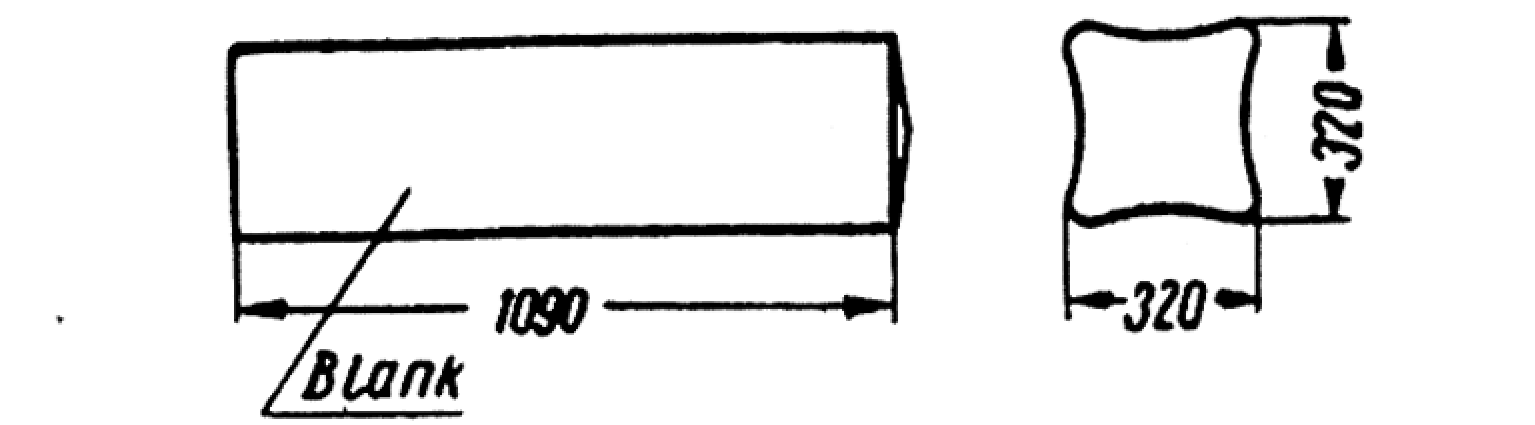
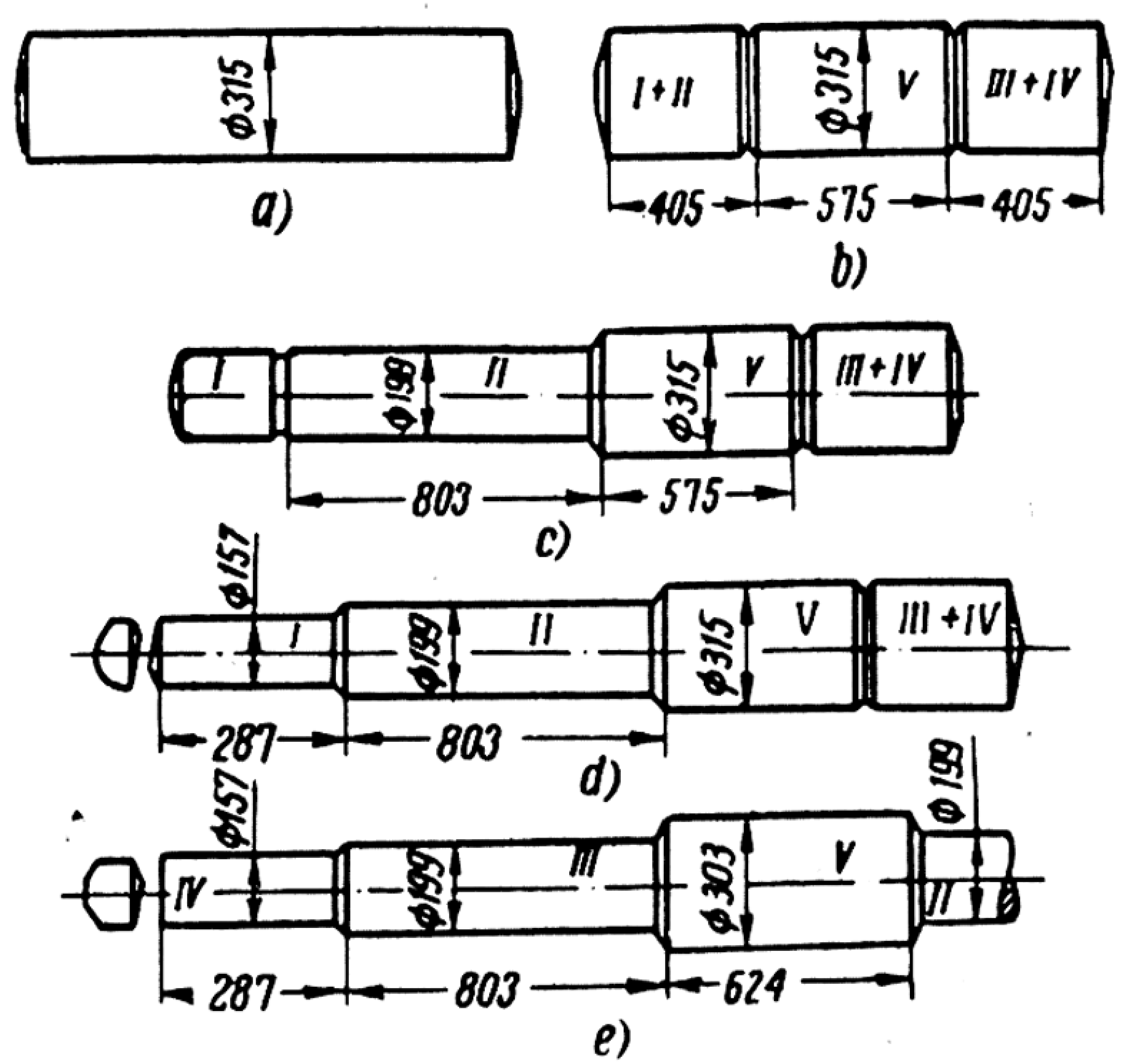
Heatings	Passes	Sketch of Passes	Equipment	Tools and implements	Forging temperature interval	
I	Cut off stock according to sketch;		5,000-kg steam hammer	Dies, hot set, folding rule, caliper	1100-800°C	Cooling forging
II	a) Draw stock to Ø 315 mm; b) groove metal for section V according to sketch; c) draw end of shaft, sections I+II to Ø199 mm and groove metal for section I; d) draw end I to Ø 157 and crop off surplus; straighten and finish sections I and II; e) draw opposite end of shaft, sections III + IV, to Ø 199. Groove metal for section IV and draw to Ø 157 mm; crop off surplus. Draw section V to Ø 303 mm; straighten and finish surface of shaft.		5,000-kg steam hammer	Top and bottom dies, fullers, folding rule, calipers, hot set	220-700°C	In air

Fig 218. Process chart for forging shaft

Flat Forgings. Flat forgings of the gear blank type are very common. Upsetting the stock is a necessary operation in making these forgings. When this is done, the direction of the fibres of the finished part will be as shown in Fig. 219. This will ensure the maximum strength of the teeth of the finished gear.

If a square piece of stock is to be upset, it will be necessary to round off its sharp corners before proceeding to the upsetting operation.

It is advisable to round off the corners of the stock *1* (Fig. 220) in order to ensure the more vigorous subsequent upsetting of the metal: by this method deeper forging is obtained together with a greater increase in the cross-section of the work. The method shown in Fig. 220 can also be employed for straightening axial misalignments which sometimes occur when work is upset between top and bottom dies *2* and *3*.

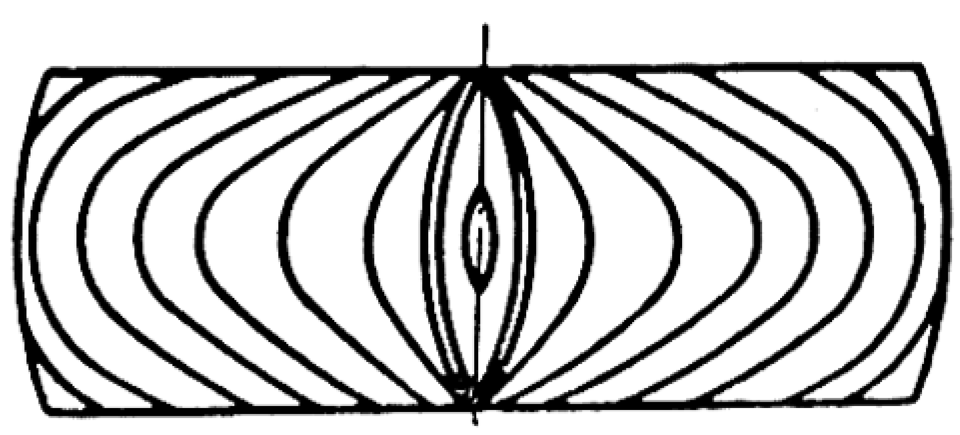


Fig. 219. Direction of fibres in a gear blank forging

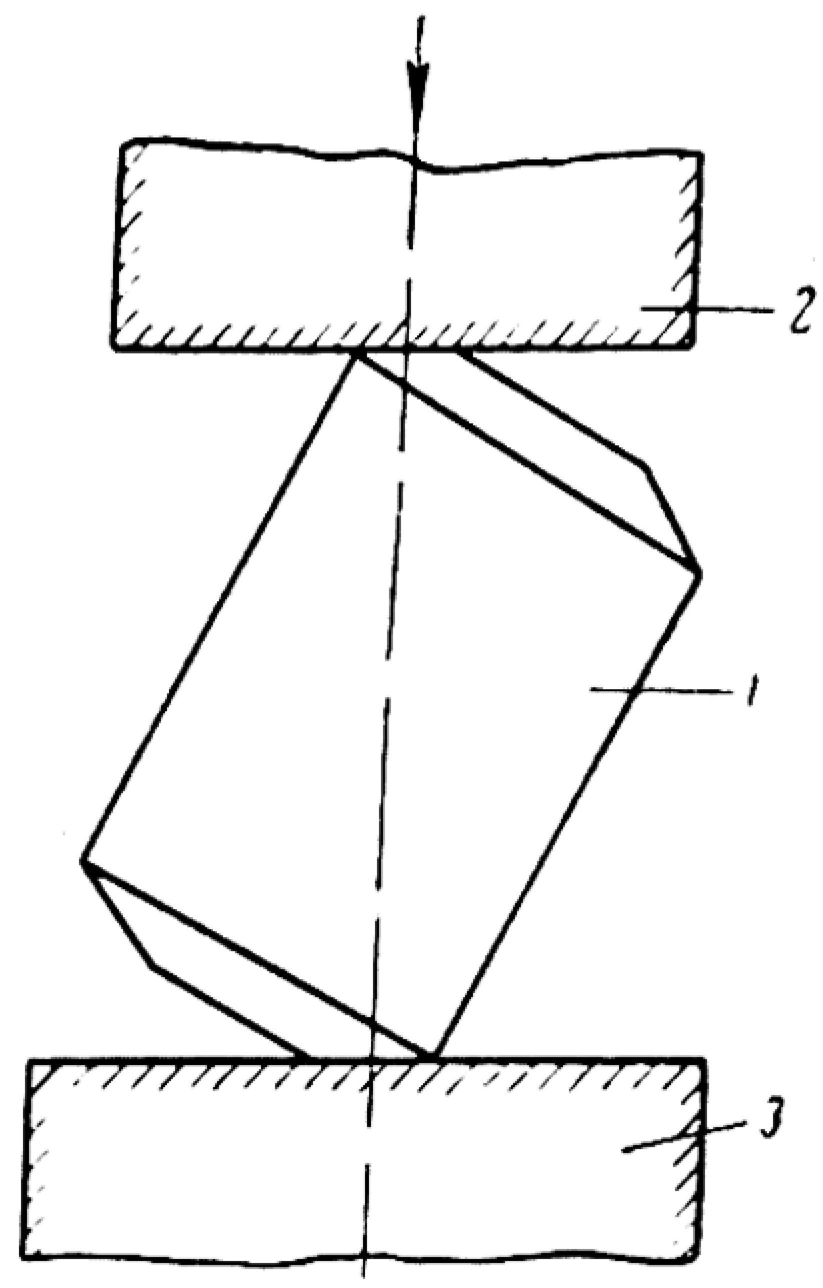


Fig. 220. Rounding the sharp corners of a piece of stock before upsetting

If the capacity of the hammer is insufficient for the final upsetting operation, fullering or spreading will have to be employed. Holes are made, as has already been described, by piercing or punching, while large holes (as, for instance, in tires and gear crowns) by rolling.

Let us now consider several examples of forming gear blanks and rings (tires).

Example 1. Required: To forge the gear blank shown in Fig. 221, *a*. Material—grade 45 steel.

1. *The forging drawing of the gear blank is first made*, outlining its contours in thin lines and indicating its dimensions, as shown in Fig. 221, *a*. For this purpose the machining allowances and forging tolerances are calculated from Appendices 7 and 8.

The allowance and tolerance for diameter $D = 528$ mm will be $a = 24 \pm 8$ mm and the allowance and tolerance for height $H = 228$ mm will be $b = 19 \pm 7$ mm. The allowance for the hole of diameter

$d = 175$ mm will be $c = 31 \pm 8$ mm. Consequently, the forging dimensions of the gear blank will be:

Diameter $D_1 = D + a = 528 + 24 \pm 8 = 552 \pm 8$ mm;

Height $H_1 = H + b = 228 + 19 \pm 7 = 247 \pm 7$ mm;

Diameter of hole, $d_1 = d - c = 175 - 31 \pm 8 = 144 \pm 8$ mm.

The diameter of the hole is taken as being 145 ± 8 mm, equal to the diameter of the punch.

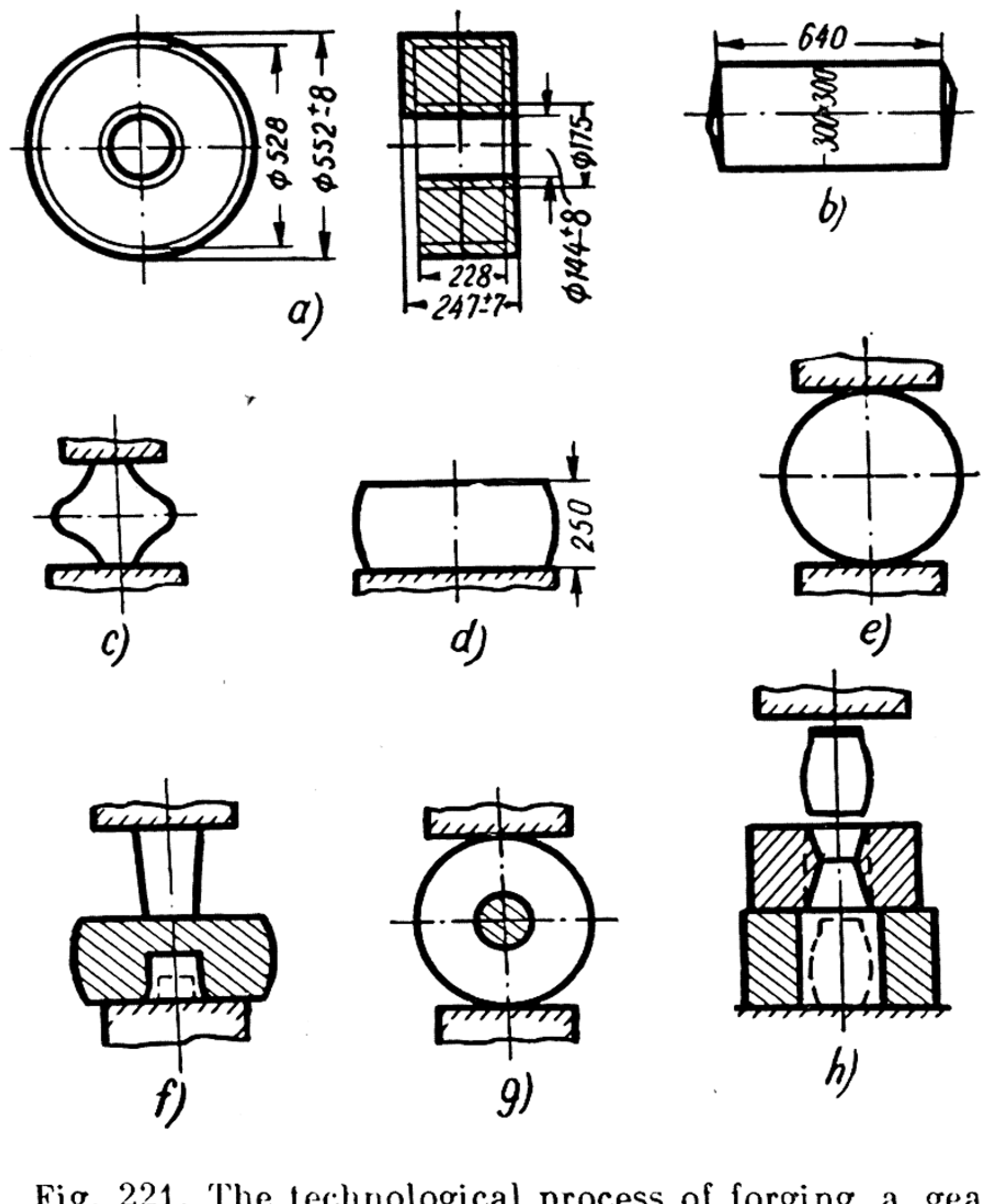


Fig. 221. The technological process of forging a gear blank:

a—forging drawing of gear blank; b, c, d, e, f, g and h—sketches of passes in forging gear blank

The outline of the forging drawing of the gear blank is now drawn in thick lines round the contour of the drawing of the finished gear blank, and the forging dimensions calculated above written in.

2. *The volume and weight of the gear blank forging are now calculated.* Its volume, V_{forg}, will be:

$$V_{forg} = \left(\frac{\pi D_1^2}{4} - \frac{\pi d_1^2}{4}\right) \times H_1 \text{ cm}^3.$$

On substituting:

$$V_{forg}=\left(\frac{3.14\times 55.2^2}{4}-\frac{3.14\times 14.5^2}{4}\right)24.7=55{,}032\ \text{cm}^3.$$

The weight of the forging, W_{forg}, will be:

$$W_{forg}=V_{forg}\ g=\frac{55{,}032\times 7.85}{1{,}000}=432\ \text{kg}.$$

3. *The volume, weight and dimensions of the stock are now calculated.*

Its volume, V_{stock}, will be equal to:

$$V_{stock}=V_{forg}+V_{waste}+V_{sc}\ \text{cm}^3.$$

In this case, the waste entailed will be that of the slug formed when punching the hole for the shaft. Presuming that the hole is made with a punch 145 mm in diameter, and that the height *(h)* of the slug is equal to one-third of the full height H_1 of the forging, the volume of the slug, V_{sl}, will be:

$$V_{sl}=\frac{\pi d^2}{4}h\ \text{cm}^3,$$

the height of the slug $h=\frac{H_1}{3}=\frac{247}{3}=82$ mm,

the volume of the slug, V_{sl}, will be:

$$V_{sl}=\frac{\pi d^2}{4}h=\frac{3.14\times 14.5^2}{4}\times 8.2=1{,}353\ \text{cm}^3.$$

Assuming that the forging will require two heatings, the volume of the loss due to scale will be 3.5 per cent of the volume of the stock.

Volume of forging together with slug 55,032+ 1,353= 56,385 cm³.

Volume of steel lost as scale

$$V_{sc}=56{,}385\times 0.035=1{,}973\ \text{cm}^3.$$

Total volume of stock, V_{stock}=55,032+ 1,353+ 1,973= 58,358 cm³.

Weight of stock,

$$W_{stock}=\frac{58{,}358\times 7.85}{1{,}000}=458\ \text{kg}.$$

4. *The weight of the falling parts (the capacity) of the hammer is now selected.* According to the chart in Fig. 176, a forging 552 mm in diameter and 247 mm in height can be made on a hammer with falling parts weighing 5,000 kg.

5. *Calculating the dimensions of the stock.* When calculating the dimensions of the stock for gear blank-type forgings, it is always necessary to take into consideration the stroke (travel) of the ram of the hammer on which the forging is to be made. As a rule, the cross-section of the stock to be forged should be as large as possible in com-

parison with its length; this ensures that the stock will be short in length, which facilitates upsetting, since the idle travel of the ram will be longer and, consequently, the force of the impact greater. The maximum length of the stock must not exceed 2.5 diameter or 2.5 times the length of the side of the square, if it is a square bar.

Presuming that the gear blank is to be forged from a 300× 300 mm square billet, the cross-sectional area of the billet will be:

$$A_{stock}=30\times30=900\ \text{cm}^2.$$

The length of the stock, L_{stock}, is calculated from the formula:

$$L_{stock}=\frac{V_{stock}}{A_{stock}}=\frac{58{,}358}{900}=64.8\ \text{cm}.$$

The ratio of the length of the stock to the length of the side of the square is $\frac{64.8}{30.0}=2.16$; this is less than the maximum permissible ratio 2.5. Consequently, the correct cross-section for the stock has been selected.

Thus, for making this forging a square piece of stock of length 650 mm and cross-section 300×300 mm, will be selected.

6. *The forging operations for making the gear blank are now chosen and its intermediate forging dimensions calculated.*

1) Cut off piece of stock to length from a billet (Fig. 221, *b*);
2) Round off stock between flat dies (Fig. 221, *c*);
3) Upset stock to height of forging $H=250$ mm (Fig. 221, *d*);
4) Forge to diameter (Fig. 221, *e*);
5) Make hole with punch of $d=145$ mm (Fig. 221, *f*);
6) Hammer forging all round, without removing punch (Fig. 221,*g*);
7) Size (calibrate) hole (Fig. 221, *h*);
8) Flatten (swage) faces of gear blank.

Forging temperature interval 1,200-750° C.

Tools and fixtures for operations: 1st operation—flat top and bottom dies, hot set, cutter extensions; 2nd and 3rd operations—flat top and bottom dies; 4th and 5th operations—flat top and bottom dies, punch; 6th and 7th operations—flat top and bottom dies; finish punch, ring.

Example 2. Required: to forge the ring (tire) shown in Fig. 222. Allowances and tolerances are selected from the tables of Appendix 8 and the forging drawing of the tire made (Fig. 222, *a*).

1. *Calculating the volume and weight of the forging.* Volume:

$$V_{forg}=\frac{(\pi D^2-\pi D_i^2)}{4}H\ \text{cm}^3,$$

where D — outside diameter of tire equal to 820 ± 9 mm,
D_i — inside diameter of tire equal to 640 ± 9 mm,
H — height of ring, equal to 190 ± 6 mm.

$$V_{forg} = \left(\frac{3.14 \times 82^2}{4} - \frac{3.14 \times 64^2}{4} \right) 19 = 39{,}216 \text{ cm}^3.$$

Weight of forging $W_{forg} = V_{forg}\, g$ kg,

$$W_{forg} = \frac{39{,}216 \times 7.85}{1{,}000} = 308 \text{ kg}.$$

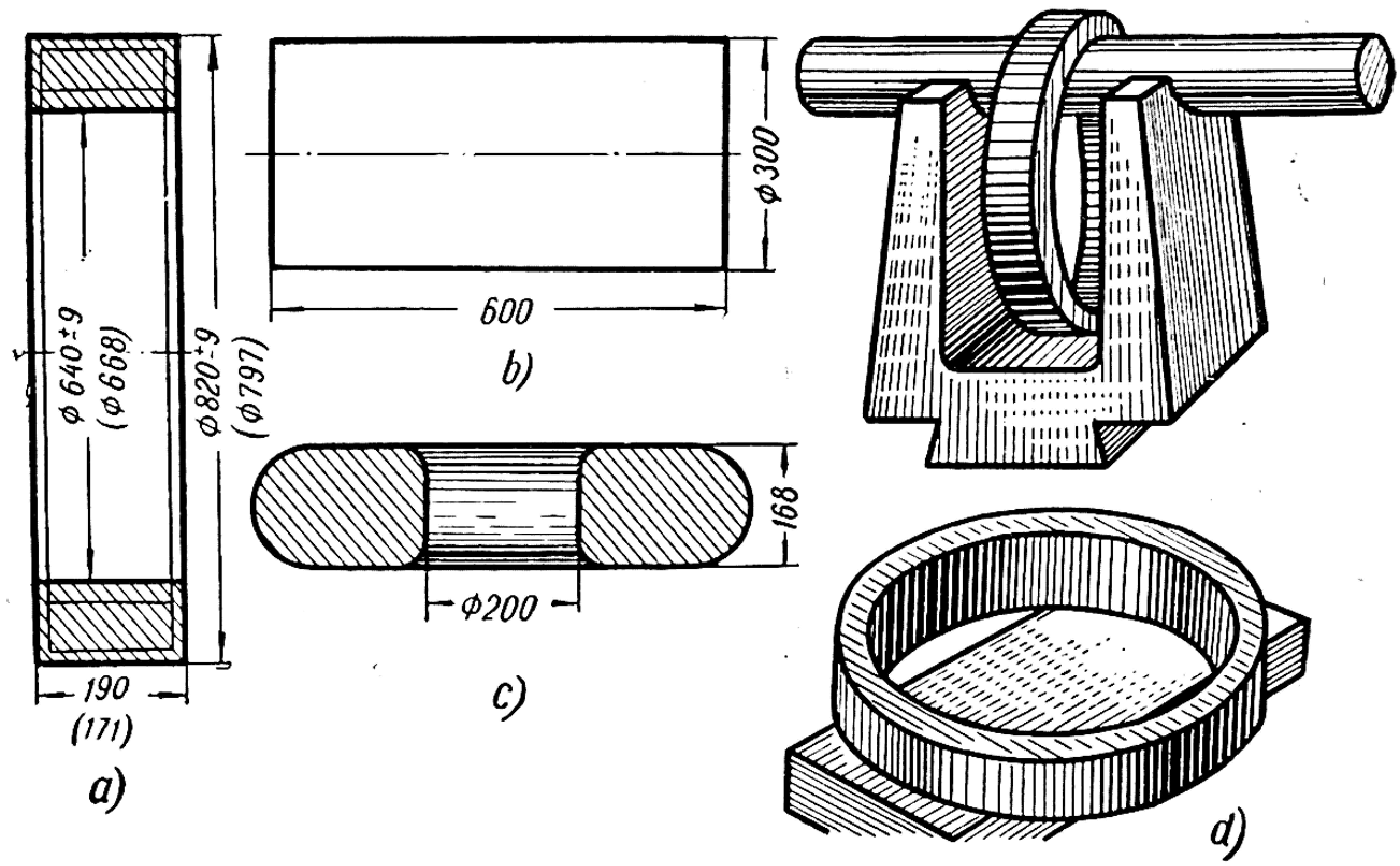


Fig. 222. Technological process of forging a ring (tire):
a—forging drawing of a tire; b, c, and d—sketches of passes in forging tire

2. *Calculating the volume and weight of the stock.* The volume of the stock, V_{stock}, required for making the forging will be:

$$V_{stock} = V_{forg} + V_{sl} + V_{sc} \text{ cm}^3.$$

It is taken that the diameter d of the hole in the tire before rolling is 200 mm. The hole will be punched. The height of the slug is $\frac{h}{3}$, where h is the height of the upset stock of the ring before rolling.

The height of the upset stock before rolling can be calculated from the formula:

$$h = 1.05\, kH,$$

where k—the expansion factor,
H—height of forging, in mm.

The expansion factor k is taken from the chart in Fig. 223. For this tire, the rolling factor q and the ratio $\frac{H}{D}$ will be:

$$q=\frac{D_i}{d}=\frac{640}{200}=3.2; \quad \frac{H}{D}=\frac{190}{820}=0.23.$$

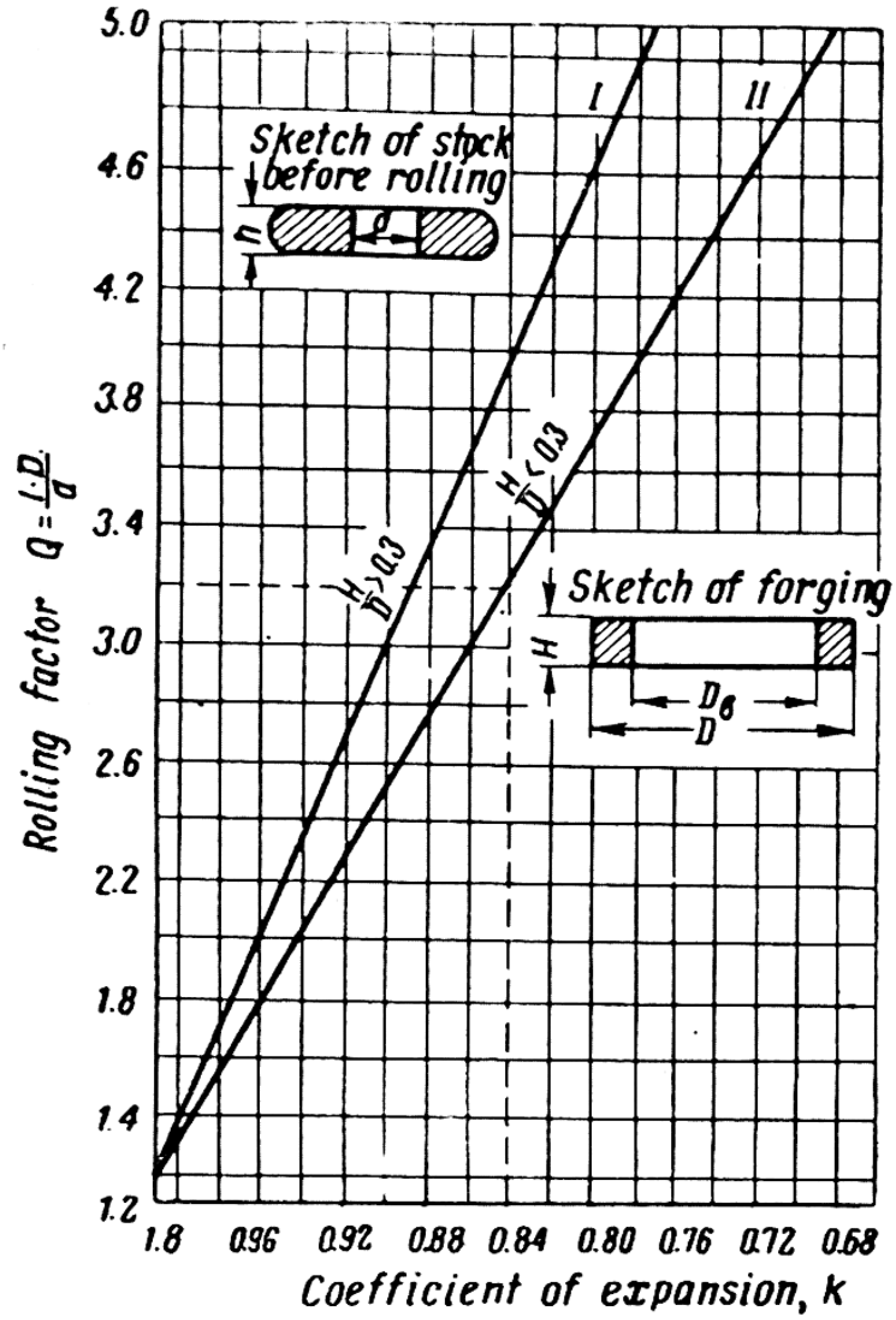


Fig. 223. Chart for determining height of upset piece of stock

From point 3.2 on the coordinate marked "rolling factor q", a line is drawn parallel to the coordinate marked "expansion factor k" until it intersects straight line II for $\frac{H}{D}<0.3$. From this point of intersection, a perpendicular is dropped to coordinate k and the expansion factor $k=0.84$ found. Consequently, the height of the stock before rolling will be:

$$h=1.05\times0.84\times190=168 \text{ mm}.$$

And the volume of the slug will be:

$$V_{sl}=\frac{\pi d^2}{4}\times\frac{h}{3}=\left(\frac{3.14\times20^2}{4}\right)\frac{16.8}{3}=1{,}758 \text{ cm}^3.$$

The tire is to be forged in two heatings, hence the loss of metal due to scale is taken as 3.5 per cent of the volume of the stock. The volume of the forging together with the slug will be:

$$39{,}216+1{,}758=40{,}974 \text{ cm}^3.$$

The volume of the metal lost due to scale, V_{sc}, will be:

$$V_{sc}=40{,}974\times 0.035=1{,}434 \text{ cm}^3.$$

The volume of the forging, V_{forg}, will be:

$$V_{forg}=39{,}216+1{,}758+1{,}434=42{,}408 \text{ cm}^3.$$

Its weight, W_{forg}, is calculated from the formula:

$$W_{forg}=V_{forg}\times g=\frac{42{,}408\times 7.85}{1{,}000}=333 \text{ kg}.$$

3. *Calculating the dimensions of the stock.* A billet of diameter (d) 300 mm is selected for making the forging.

The cross-sectional area of the billet, A_{forg}, will be:

$$A_{forg}=\frac{\pi d^2}{4}=\frac{3.14\times 30^2}{4}=706.9 \text{ cm}^2.$$

The height of the stock, h_{stock}, will be:

$$h_{stock}=\frac{42{,}408}{706.9}=59.9\approx 60 \text{ cm}.$$

Ratio of stock height to diameter

$$n=\frac{60}{30}=2,$$

i. e., the calculated dimensions of the stock meet the requirements necessary to ensure upsetting without buckling.

A billet 300 mm in diameter and 600 mm long will be used.

4. *Specifying the forging operations* and *calculating the intermediate forging dimensions*:

1) Cut stock to length from the billet (Fig. 222, *b*);

2) Upset stock under flat dies to height h=168 mm (Fig. 222, *c*), i. e., to a height 22 mm less than that of a tire, to allow for expansion of the tire during rolling, and also for straightening its faces after rolling;

3) Punch hole with 200 mm diameter (Fig. 222, *c*);

4) Roll (saddle) ring on mandrel 150-175 mm diameter and straighten edges (Fig. 222, *d*).

Tools and fixtures required: for the 1st operation—hot set, hot set extension, flat top and bottom dies; the 2nd operation—flat top and bottom dies; the 3rd operation—flat top and bottom dies, punch; the 4th operation—flat top die, saddle, mandrel.

Flat Forgings with Bosses. Flat forgings with bosses are made with the aid of rings (see Figs. 211 and 213). Suppose a gear blank with one boss has to be forged, as shown in the forging drawing of the gear blank in Fig. 224.

1. *First of all the volume and weight of the gear blank forging are calculated.*

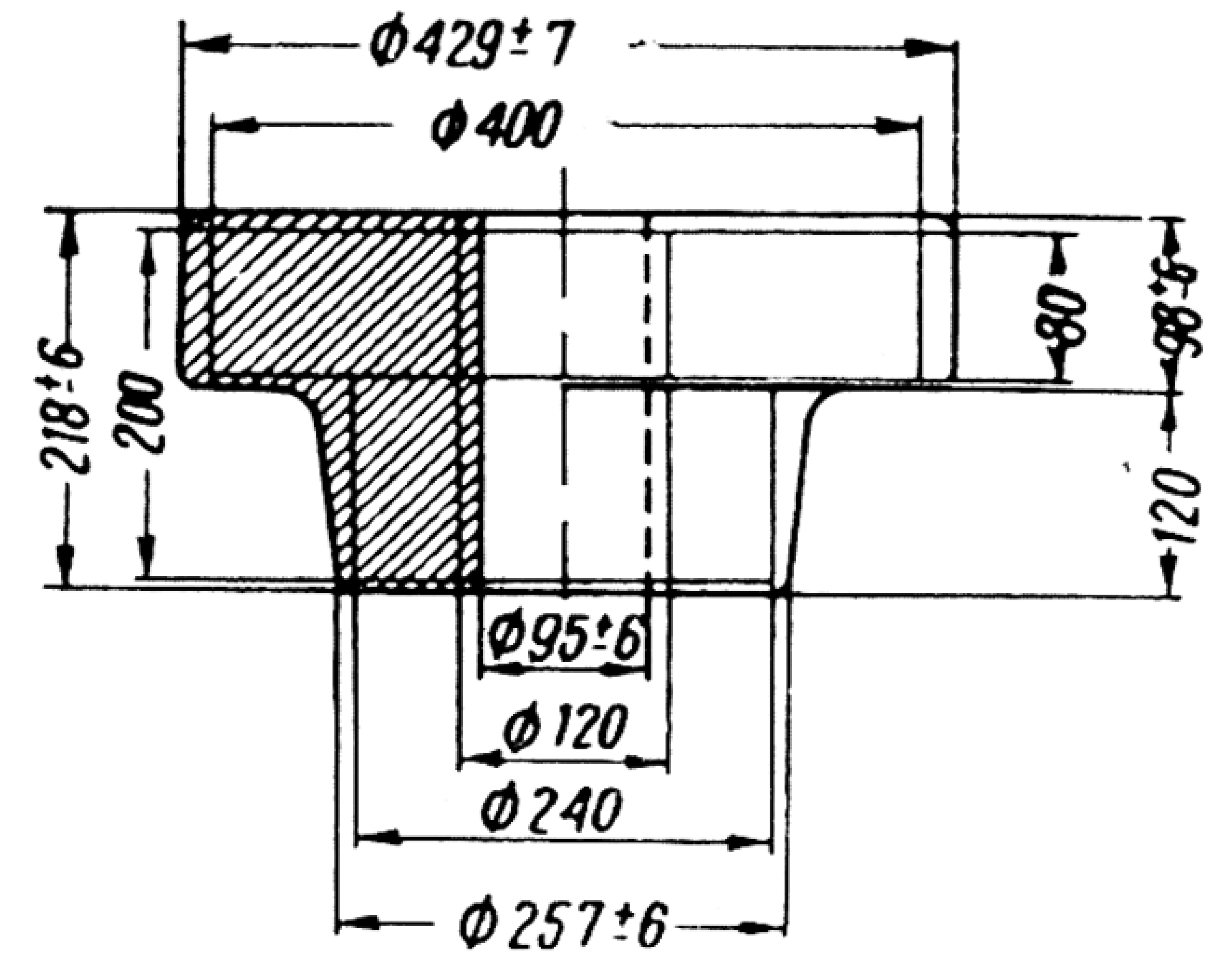


Fig. 224. Forging drawing of gear blank with boss

Volume of section I, V_1 (the boss), will be:

$$V_1=\left(\frac{\pi d^2}{4}-\frac{\pi d_1^2}{4}\right)h_1=\left(\frac{3.14\times 25.7^2}{4}-\frac{3.14\times 9.5^2}{4}\right)12=$$
$$=(518.7-70.8)\,12=447.9\times 12=5{,}375\ \text{cm}^3;$$

volume of section II, V_2 (gear blank itself), will be:

$$V_2=\left(\frac{\pi D^2}{4}-\frac{\pi d_1^2}{4}\right)h_2=\left(\frac{3.14\times 42.9^2}{4}-\frac{3.14\times 9.5^2}{4}\right)9.8=$$
$$=(1{,}445-70.8)\,9.8=1{,}374.2\times 9.8=13{,}467\ \text{cm}^3;$$

the volume of the forging will be:

$$V_{forg}=5{,}375+13{,}467=18{,}842\ \text{cm}^3;$$

the weight of the forging, W_{forg}, will be:

$$W_{forg}=\frac{18{,}842\times 7.85}{1{,}000}=148\ \text{kg}.$$

2. *Calculating the volume* and *weight of the stock*. The volume of the stock, V_{stock}, will be:

$$V_{sto\,k}=V_{forg}+V_{sc}+\ {}_{sl}\ \text{cm}^3.$$

Volume of slug:

$$V_{sl}=\frac{\pi d_1^2}{4}\frac{H}{3}=\frac{3.14\times 9.5^2}{4}\times\frac{21.8}{3}=70.8\times 7.26=514 \text{ cm}^3.$$

The forging is to be made in one heating. Consequently, the loss due to scale will be 2 per cent of the volume or weight of the stock:

$$V_{sc}=(18{,}842+514)\,0.02=387 \text{ cm}^3;$$

volume of stock

$$V_{stock}=18{,}842+514+387=19{,}743 \text{ cm}^3,$$

weight of stock

$$W_{stock}=\frac{19{,}743\times 7.85}{1{,}000}=155 \text{ kg}.$$

3. *Calculating the basic dimensions of the stock.* The gear blank will be forged by upsetting in a ring. The cross-sectional area of the stock must be now calculated. Its diameter is taken as being 250 mm. Its cross-sectional area will be:

$$A_{stock}=\frac{\pi d^2}{4}=\frac{3.14\times 25^2}{4}=490.9\approx 491 \text{ cm}^2.$$

The height (length) of the stock, l, to be upset will be:

$$l=\frac{V_{stock}}{A_{stock}}=\frac{19{,}743}{491}\approx 40.2,$$

l is taken as being equal to 400 mm.

The ratio n of the height of the stock to its diameter, will be

$$n=\frac{l}{d}=\frac{400}{250}\approx 1.6,$$

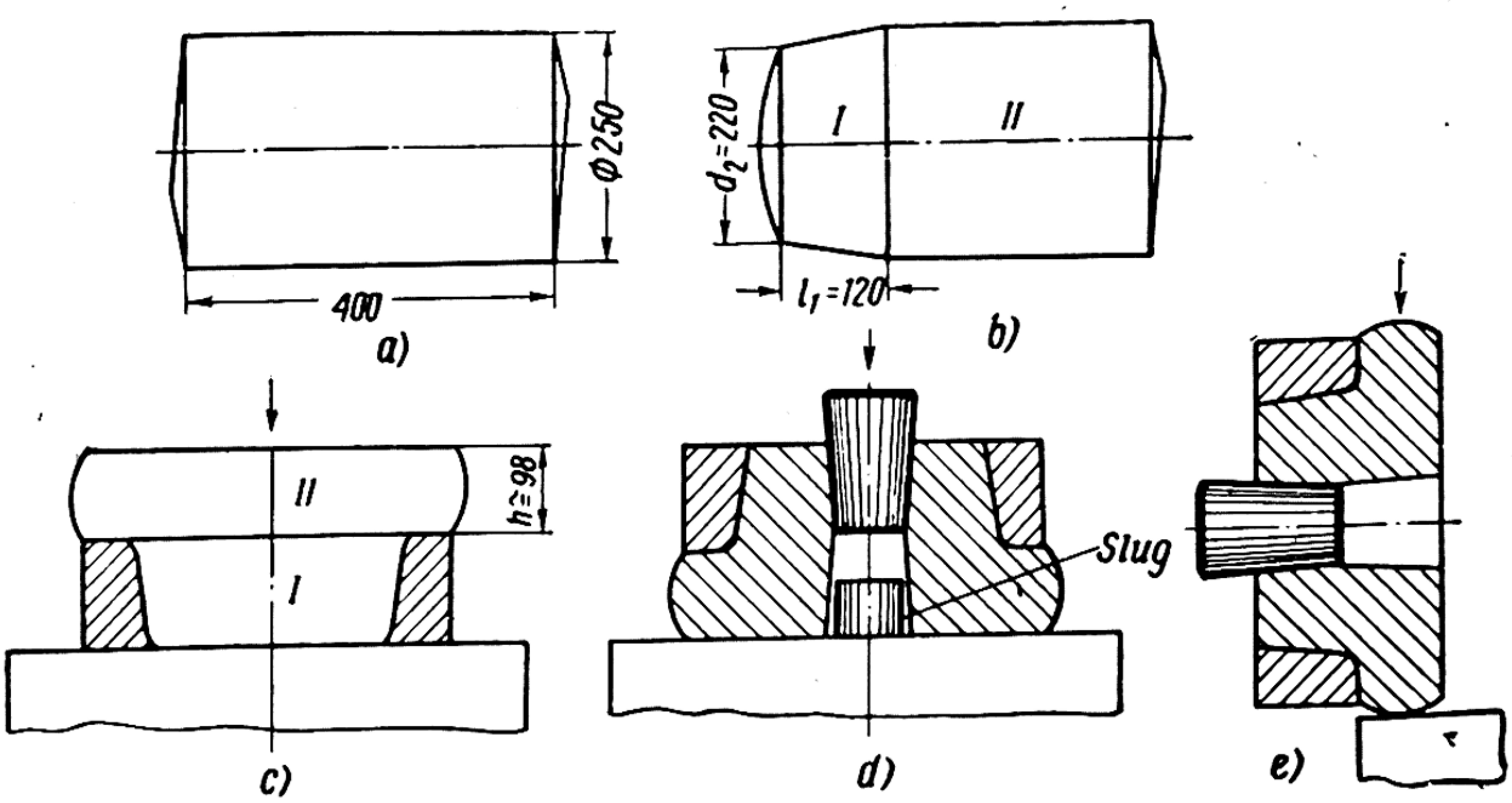


Fig. 225. Technological process of forging a gear blank with boss
a, b, c, d, and *e*—sketches of passes in forging gear blank

i. e., within the range recommended for upsetting without buckling. Thus, the dimensions of the stock will be: diameter $d = 250$ mm, length $l = 400$ mm.

4. *Determining the forging operations* and *the intermediate forging dimensions.*

Operation 1: cut stock to length from billet (Fig. 225, *a*).

Operation 2: taper draw (reduce) one end of stock (Section I) to diameter $d_2 = 220$ m; $l_1 = 120$ mm (Fig. 225,*b*).

Operation 3: upset stock for part II of forging to height $h = 98$ mm (Fig. 225, *c*). The tapered end (Part I) of the forging is inserted in the ring; and Part II of the forging is then given a series of frequent and heavy blows with the top die of the hammer. During the upsetting process, the stock must be constantly rotated, together with the ring, around its vertical axis.

Operation 4: punch hole from both sides of stock (Fig. 225, *d*).

Operation 5: hammer the circumference of the forging in the ring without removing punch, and flatten its faces (Fig. 225, *e*).

Operation 6: remove ring from boss. If the ring is made with an inside taper, it can be easily removed from the boss of the gear blank on the completion of the fifth operation. If, however, it has no inside taper, the boss will be a very tight fit inside the ring, and the latter will be very difficult to remove. In such cases, packing and supplementary rings must be employed for removing the forging.

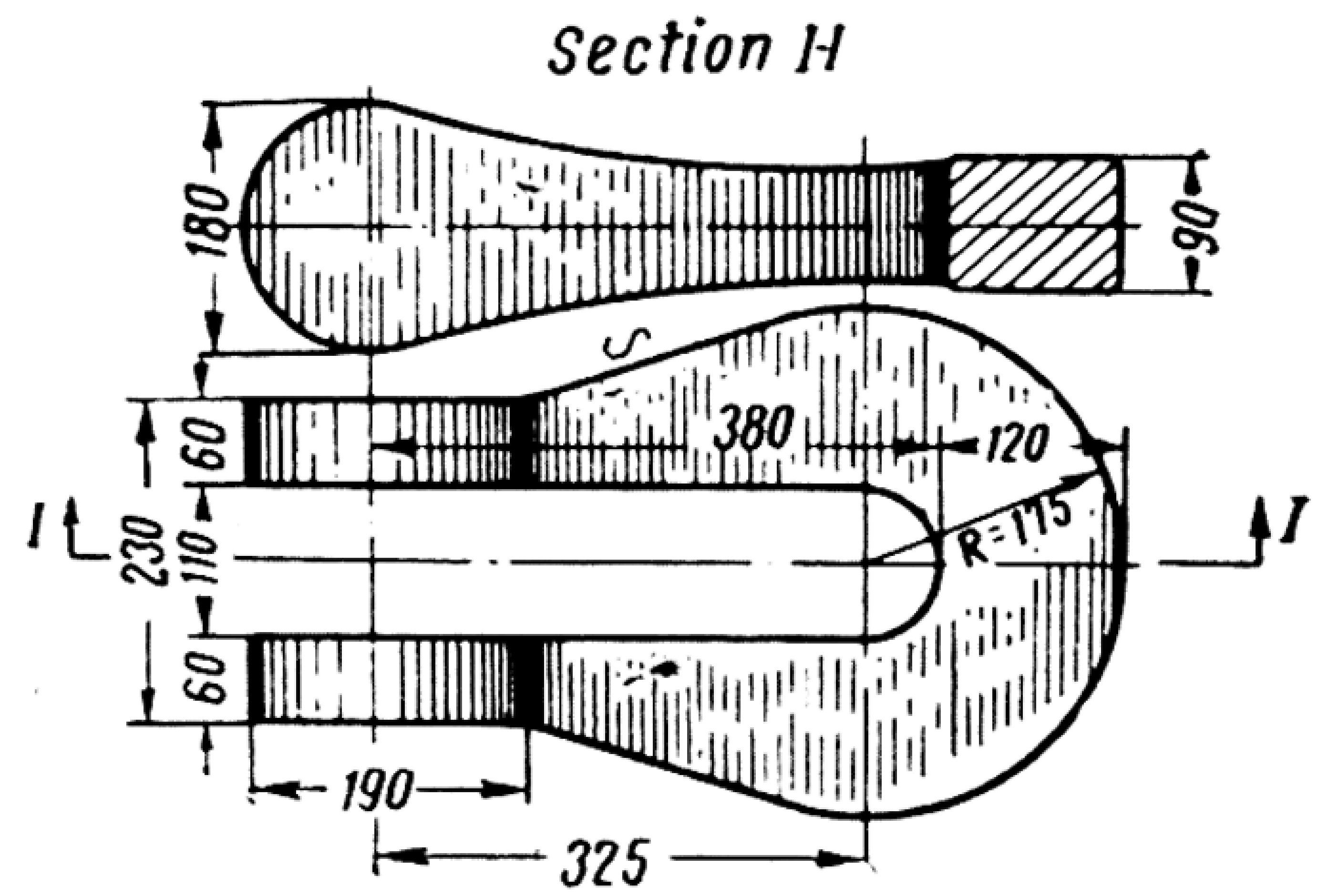


Fig. 226. Forging drawing of a shackle

Making Shaped Forgings. Special tools are usually employed for making intricate forgings, or, as they are called, shaped forgings. In most cases, it is advisable to make shaped forgings with the aid of insert dies. Shaped forgings call for creative initiative on the part of the blacksmith in addition to a good knowledge of the chief forging methods and operations. He must always try to simplify and improve technological processes.

Here is an example of the technological process for forging a shackle (Fig. 226) in a hammer with falling parts weighing 3 tons. The material to be used will be grade 45 steel, and the forging is to be a finish forging, requiring no subsequent machining. Weight of forging—125 kg.

Shackles can be forged by several different methods, but the best method will be that which will ensure high mechanical properties of the finished shackle. These can only be obtained if, during the forging process, the fibres of the steel are not cut in the direction of the forces which will be applied to the shackle during its service.

The fibres of the metal will not be cut if the shackle is made in swages by the bending process. In this case, the fibres of the metal will run parallel to the direction of the application of the forces acting on the shackle. Therefore the technology of forging the shackle, given in this example, will ensure simultaneously high mechanical properties of the work, high productivity and the minimum loss of metal as waste.

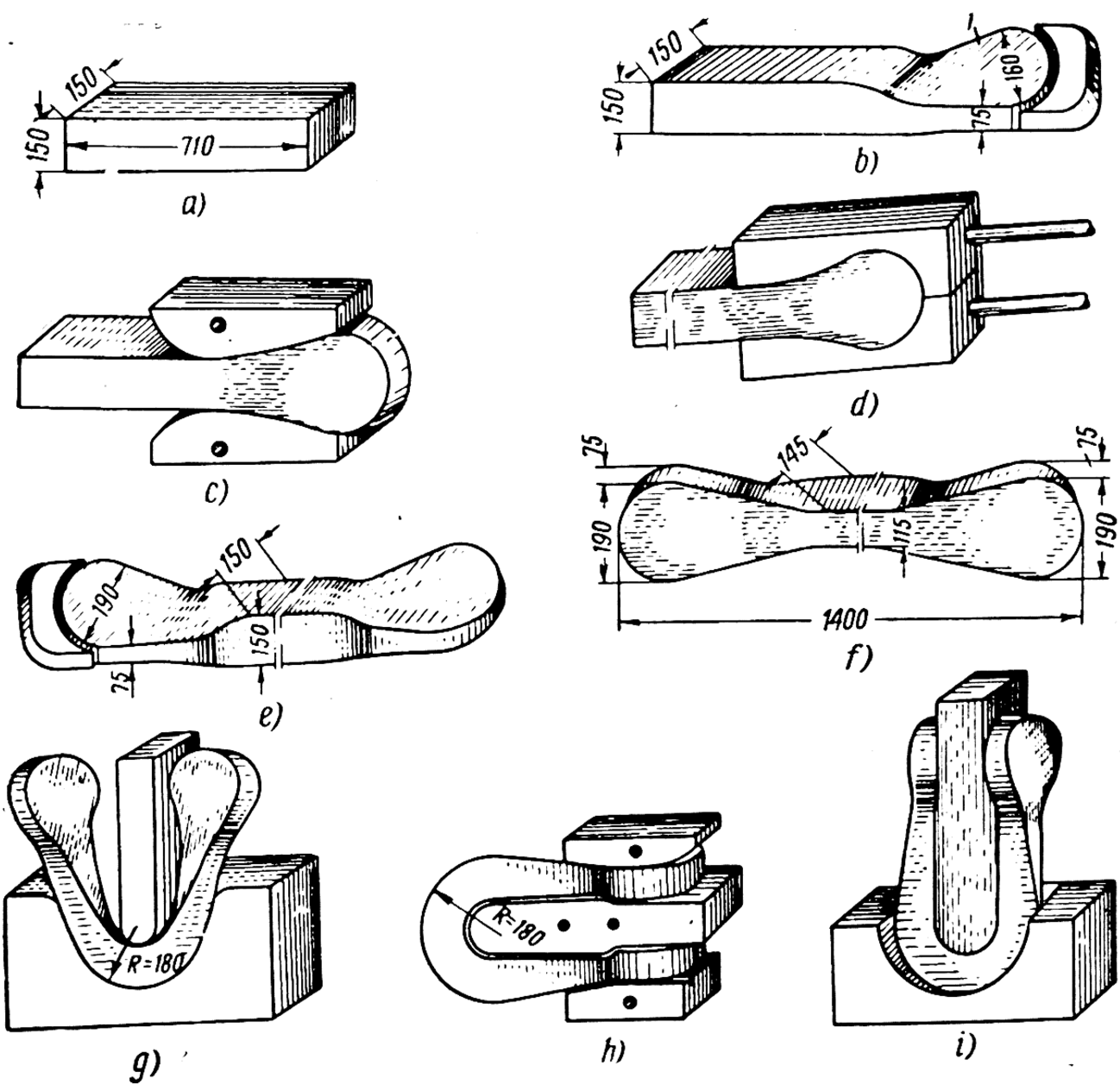


Fig. 227. Technological process of forging a shackle:
a, b, c, d, e, f, g, h and *i*—sketches of passes in forging a shackle

The *technological process* comprises the following operations:

Operation 1. Cut stock to length (Fig. 227, *a*);

Operation 2. Taper draw end I and cut with semi-circular hot set (Fig. 227, *b*);

Operation 3. Form eye with tapered sets (Fig. 227, *c*);

Operation 4. Finish form eye with the aid of swages (Fig. 227, *d*);

Operation 5. Taper draw end II and cut with semi-circular hot set (Fig. 227, *e*);

Operation 6. Form eye II with tapered sets (as in Fig. 227, *c*);

Operation 7. Finish form eye II with swages (as in Fig. 227, *d*);

Operation 8. Draw central section of stock to 115 $\times$ 145 mm (Fig. 227, *f*);

Operation 9. Bend stock with bottom swage die and mandrel (Fig. 227, *g*);

Operation 10. Finish bend stock and finish form eyes with the aid of tapered set (Fig. 227, *h*);

Operation 11. Finish head to specified dimensions with the aid of bottom swage die and mandrel. Check dimensions with template (Fig. 227, *i*).

Tools and fixtures for operations: the 1st operation—hot set; the 2nd and 5th operations—semi-circular hot set; the 3rd and 6th operations—special tapered sets; the 4th and 7th operations—special swage; the 8th operation—flat top and bottom dies; the 9th operation—special bottom swage and mandrel; the 10th operation—special tapered sets and mandrel; the 11th operation—bottom swage, mandrel and template.

CHAPTER XI

FORGING PRESSES AND THEIR OPERATION

HYDRAULIC AND STEAM HYDRAULIC FORGING PRESSES

Depending on their method of actuation, forging presses are classified as: a) hydraulic and steam-hydraulic presses and 2) presses driven by individual electric or other motors.

Hydraulic and *steam-hydraulic* forging presses are employed for heavy forgings only, while motor-driven presses are employed for die stamping and die forging.

Part of the energy of the falling parts of all hammers, whatever their design, is transferred through the bottom die and the anvil block to the foundation of the hammer and the soil, causing considerable jars and vibration which harm both the hammer itself and adjacent buildings and installations. In forging presses, however, the top die gradually transfers its pressure through the forging to the bottom die; and the design of the press ensures the transmission of this pressure to the columns of the press instead of to the foundation, thus avoiding vibration of the floor. For this reason forging presses do not require large foundations for their erection.

In hammer forging, especially when forging heavy work, the force of the blow of the die fails to penetrate the entire depth of the forging, as the speed of the ram at the moment of impact is greater than the speed of the flow (deformation) of the metal. Because of this, hammers of considerable capacity would be required to ensure the deformation of the metal throughout its entire depth when forging heavy work. When forging in presses, however, where the metal is subjected to the gradually increasing pressure of the top die instead of to instantaneous blows, the pressure succeeds in penetrating throughout the entire thickness of the forging. In addition, the efficiency of forging presses is higher than that of forging hammers.

Fig. 228 shows a schematic diagram of a *hydraulic press*. The press consists of bottom plate *1* which is connected by four steel tie rods *2* to upper plate or crown *3*. The tie rods are threaded and secured in the plates by nuts. Working cylinder *4* and plunger *5*, which is connected to slide *6*, are attached inside the crown. When water under high pressure (100-400 atmospheres) is forced into the working cylinder, the plunger, together with the slide, will descend. Top

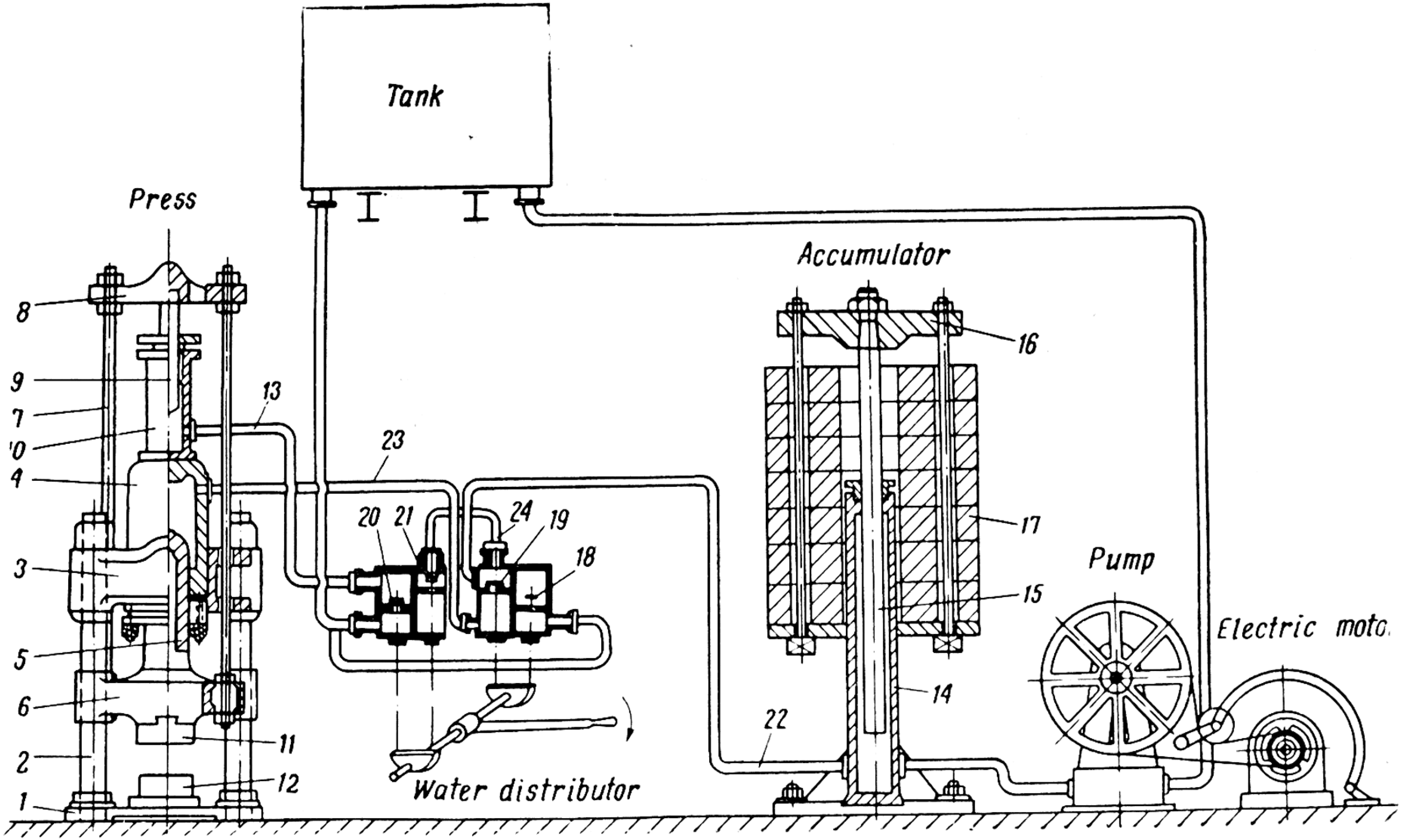


Fig. 228. Schematic diagram of a hydranlic press:

1) bottom plate; 2) tie rods; 3) crown; 4) working cylinder; 5) plunger; 6) slide; 7) connecting rod; 8) cross head; 9) pull-back cylinder plunger; 10) pull back cylinder; 11) top die; 12) anvil (bottom die); 13) water line; 14) load accumulator cylinder; 15) piston; 16) cross head; 17) counterweights; 18, 19, 20, 21) valves; 22, 23, 24) pipelines

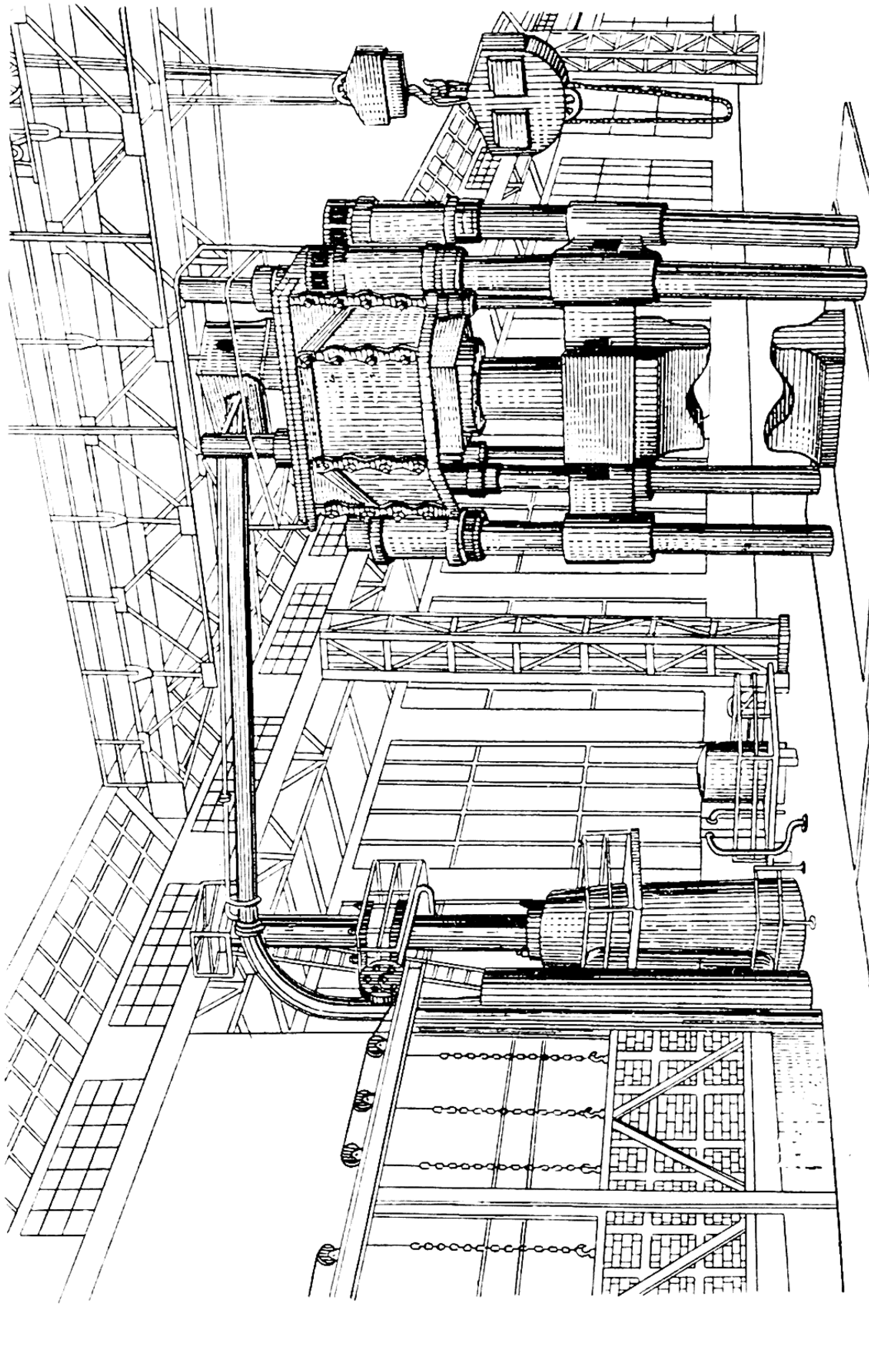


Fig. 229. Forging press installed in shop

die *11* is secured to the slide, and bottom die *12*—to the bottom bed plate. Under the pressure of the top die a piece of hot metal or ingot placed on the bottom die will be squeezed (deformed). The slide can be raised by pull-back cylinder *10*.

This forging press is equipped with only one working cylinder; presses of greater capacity (3,000-10,000 tons), however, are built with two or three working cylinders. This means that various pressures (for instance, of 1,500 to 3,000 or even to 10,000 tons) can be obtained by connecting or disconnecting as required the corresponding cylinders. Medium capacity hydraulic forging presses are built with tables capable of travelling along the longitudinal axis of the press, while those of greater capacity have tables capable of longitudinal and transverse travel.

Fig. 229 shows a general view of a hydraulic press installed in a press shop.

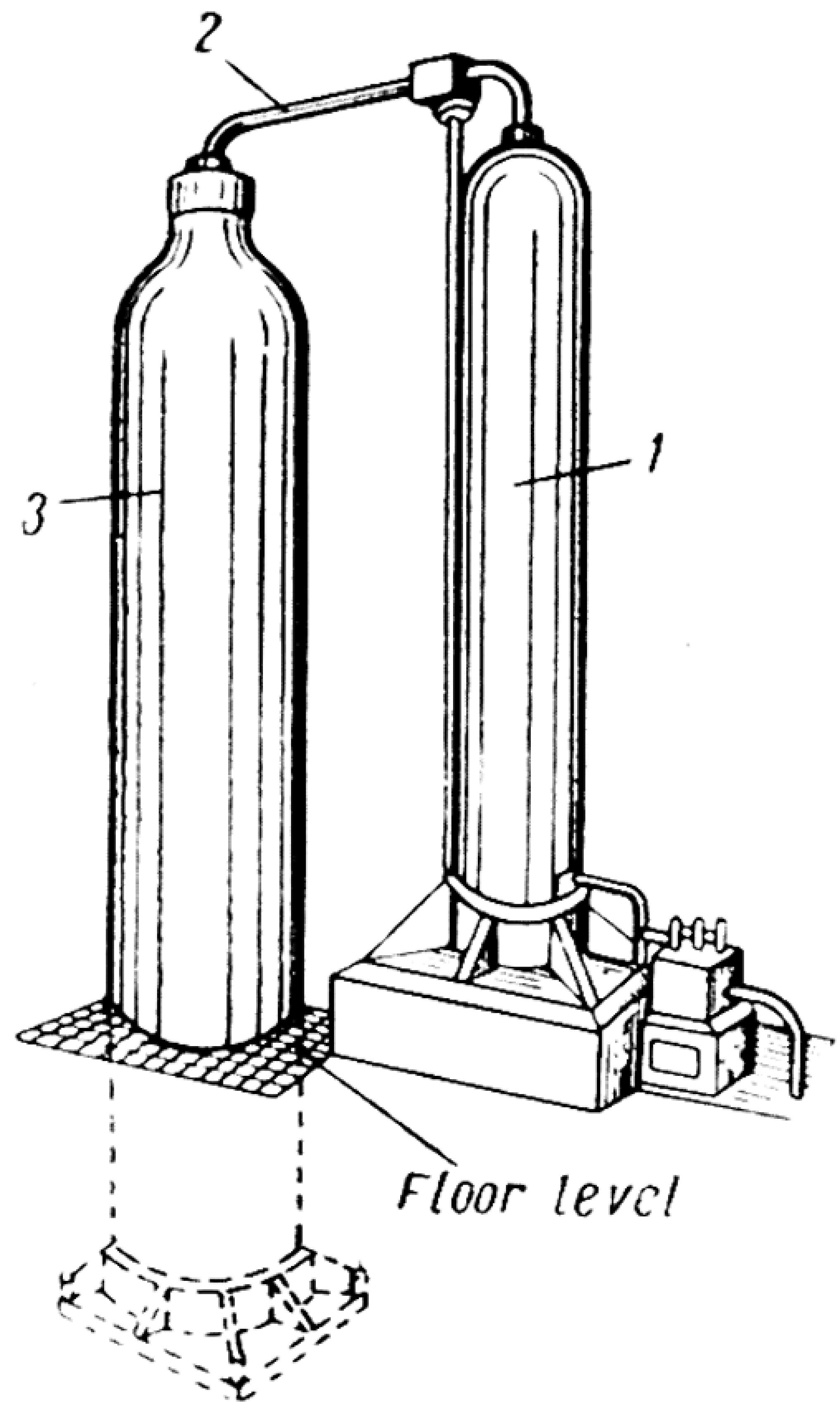


Fig. 230. Air accumulator

In hydraulic forging presses, water under high pressure is delivered by electric motor-driven pumps; the water is stored up in accumulators or pre-fillers as they are also called. These pre-fillers can be air or weight operated. *Weight-operated pre-fillers* work on the following principle: a heavy load, suspended from a crossbar coupled to a piston, compresses the water confined in a cylinder, thereby forming a reserve of water under high pressure. These accumulators, however, are very clumsy and are no longer built today; air-operated accumulators have taken their place.

Air accumulators without pistons are a more modern type of accumulator. Fig. 230 shows such an accumulator, which operates as follows: water is pumped into steel cylinder *1*, which is filled with water to about three-quarters of its capacity; the remaining space is filled with compressed air delivered from compressed air cylinder *3* through compressed air pipe *2*. In this way, the surface of the water in cylinder *1* is under a constant pressure of compressed air, which acts in the same way as the load in the weight-operated accumulators.

Fig. 231 shows a *diagrammatic scheme of a hydraulic forging press installation*. It consists of hydraulic press *A*, distributor *C*

and pre-filler *B*, containing water under a pressure of 3-9 atmospheres of air.

In order to lower slide *8*, lever *1* must be placed into position II, when valve *5* will open, and valves *2*, *3* and *4* will be closed. Working cylinder *9* of the press will be rapidly filled with water flowing

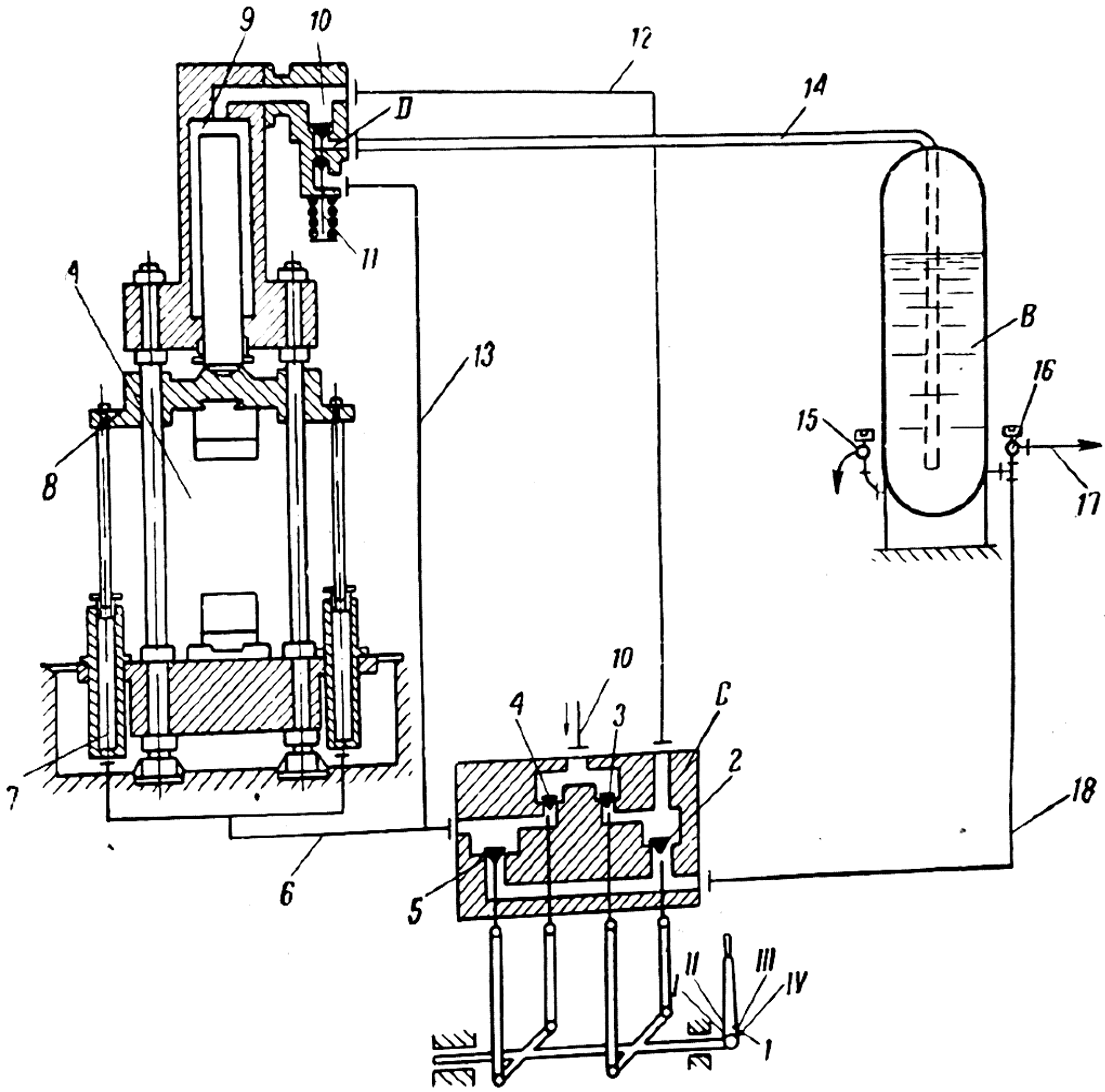


Fig. 231. Diagram of hydraulic press

along pipe *14* from pre-filler *B*, since the pressure of the water will open valve *10*. From the lifting cylinders *7* and servo-motor *11*, the water will flow into the overflow tank through valve *5* and pipeline *17*. By further moving lever *1* to position I, valve *3* will be opened, water under high pressure will then be forced into cylinder *9* along high-pressure pipe *12* and valve *10* will be closed by the pressure of the water. The water under high pressure will act on the piston which will transmit the pressure to slide *8* and the top die; as a result, the metal on the bottom die is squeezed and deformed.

To lift the slide together with the top die, lever *1* must be shifted to position IV, thereby opening valves *2* and *4* and closing valves *3* and *5*. The water under high pressure will then enter pull-back cylinders *7* through high-pressure pipe *6*, and force the piston and tie-rods to raise slide *8*. The pressure of the piston will force the wa-

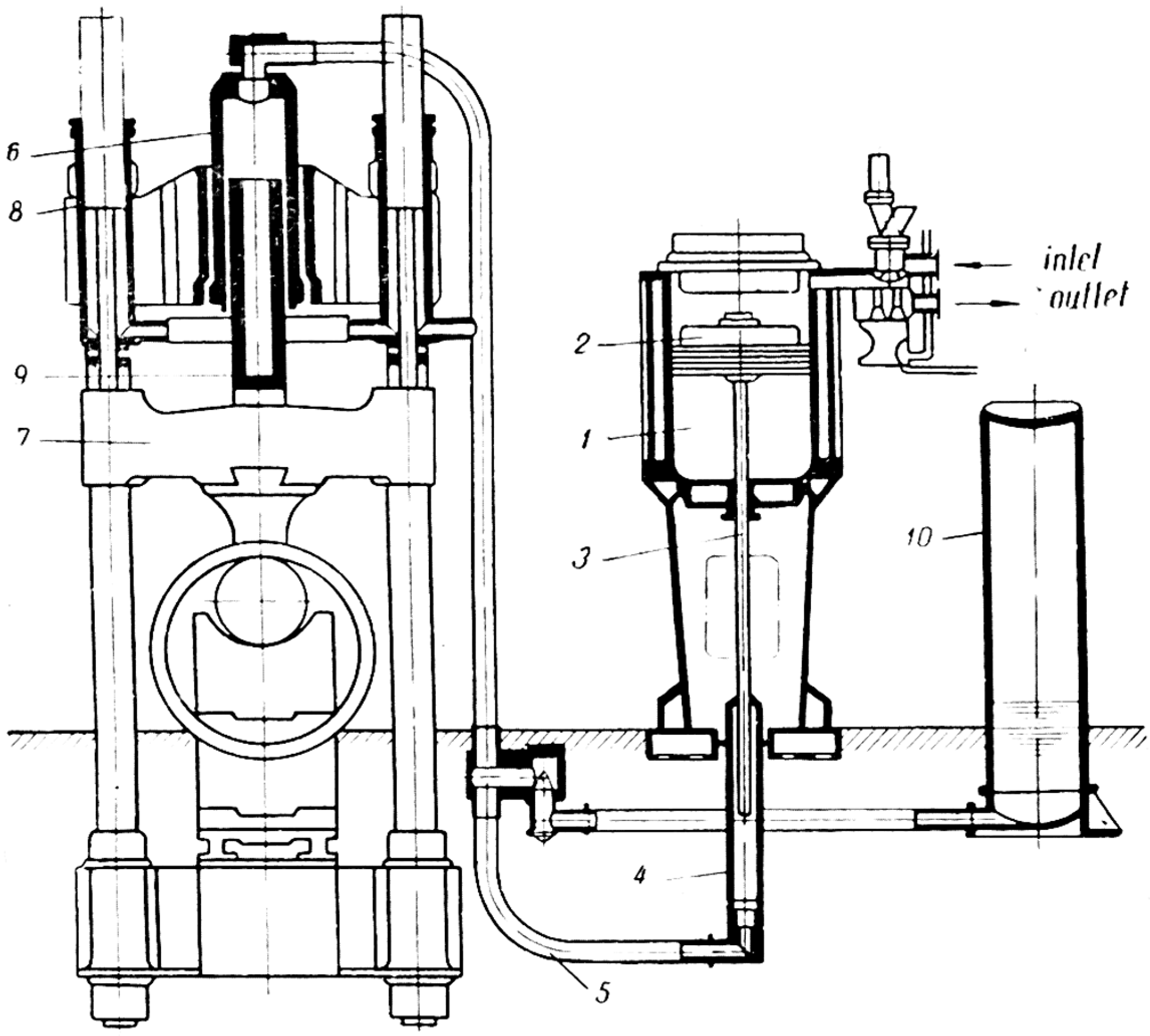


Fig. 232. Press with steam-hydraulic intensifier:
1) intensifier cylinder; 2) piston; 3) piston rod; 4) hydraulic cylinder; 5) pipeline; 6) press cylinder; 7) slide; 8) lifting cylinder; 9) plunger; 10) tank

ter from the working cylinder along water line *12* and through valve *2* into the discharge tank; a portion of the water will flow through valve *10* supported by rod *D* of servo-motor *11* into pre-filler *B*. Any excess water will be discharged from pre-filler *B* through valves *15* and *16* along water line *17* into the overflow tank. In order to hold slide *8* in the suspended position, lever *1* must be shifted into position III, thereby opening valve *2* and closing valves *3*, *4* and *5*.

Nowadays hydraulic forging presses are being built for producing medium heavy forgings only, steam-hydraulic presses being employed

for producing heavy forgings. *Steam-hydraulic presses* differ only slightly from ordinary hydraulic presses, having so-called intensifiers, operated by steam or compressed air, instead of a pump and accumulator. Fig. 232 shows a schematic diagram of a forging press equipped with a steam-hydraulic intensifier.

The *intensifier* comprises large cylinder *1* inside which travels piston *2*, rod *3* of which is located inside cylinder *4*. From this cylinder water under a pressure of 300-400 atmospheres is forced along high-pressure pipeline *5* into the working cylinder *6* of the press. Slide *7* is connected by tie-rods to the piston of the pull-back cylinders *8*, designed for raising slide *7* and working cylinder plunger *9* connected to it. If slide *7* is to be lowered and, with it, the top die, cylinder *6* is filled with low-pressure water from low-pressure tank *10*; this will force the plunger downwards and, when the top die contacts the forging, the low-pressure line will be disconnected from low-pressure tank *10* and steam will flow into intensifier cylinder *1*; the pressure of this steam on plunger *9* is transmitted to the water in hydraulic cylinder *4*, whence it flows along pipeline *5* into working cylinder *6*. There it brings the water to a high pressure which is transmitted through the working cylinder plunger of slide *7* and to the top die.

Though the operating conditions of forging presses are more favourable than those of forge hammers, since they are not subject to such severe shocks, their maintenance must be no less careful, as the various parts of the press are under constant high pressure. The high-pressure water lines in particular are subject to frequent breakdowns. The flanges of all pipelines must always be tightly drawn up, and no leakage whatsoever allowed. Water must not be permitted to leak from sleeves through the plunger; worn sleeves should always be replaced, as they lead to leakage of the water and, consequently, to loss of pressure.

While in hammers the force of the blow of the dies is transmitted to the foundation, in forging presses the pressure is taken up by the columns, or tie-rods, along which the slide travels; for this reason, all nuts on the tie-rods must be always tightly drawn up and carefully checked. The slide must travel along the rods with a minimum possible clearance; they should also always be kept in strict alignment, as misalignment may lead to breakages. Before starting work, the tie-rods must be copiously greased. In winter, on days when the press is not in operation, the cylinders and pipelines should be warmed to prevent the water in them from freezing. The water-distributing valves are a very important part of the press, and its operation depends to a high degree on their condition; for this reason, great attention must be paid to keeping them in good condition and seeing that they are properly ground in.

SELECTING THE REQUIRED PRESSURE OF A PRESS

The pressure necessary to forge any given work in a press is selected according to the same requirements which must be met when selecting the capacity of a forging hammer. The pressure depends on the cross-sectional area of the forging.

The required pressure can be calculated by the following formula

$$P = \delta A \text{ kg},$$

where P—pressure developed by the press, in kg,

δ — tensile strength of the metal at the forging temperature in kg/cm^2,

and A—area of contact of the top die and forging in cm^2.

The required pressure for making the forging is calculated for the two chief forging operations—upsetting and reducing (drawing).

In upsetting, the area A of contact between the top die and the forging will be:

$$A = \frac{\pi d^2}{4}, \quad \text{or} \quad A = \frac{3.14 d^2}{4} = 0.785 d^2.$$

In reducing, this area will be:

$$A = bl,$$

where b—width of the forging,

and l—length of feed, i. e., the length of that section of the forging directly under the die of the press.

Table 8 gives the maximum tensile strength of certain steels at various temperatures.

Table 8

Tensile Strength of Certain Steels at Various Temperatures

Metal	Tensile strength, kg/mm², at various temperatures, °C								
	15-20°	600°	700°	800°	900°	1000°	1100°	1200°	1300°
Steel A . . .	40	12	7.2	6.25	5	3.1	2.5	2	1.8
Steel B . . .	60	25	16.2	11.2	7.6	5.5	3.7	2.5	2.0
Steel C . . .	80	37.5	24.5	17.5	11.0	7.0	4.9	3.1	2.5
Steel D . . .	100	52	32	21	13.5	8.5	6.2	3.8	2.6

The pressure required for drawing (reducing) operations can be selected from Table 9, compiled by engineer M. Storozhev.

Table 9

Selection of Pressures of Hydraulic Forging Presses

Pressure, tons	Diameter of ingot or stock, mm		Pressure, tons	Diameter of ingot or stock, mm	
	Minimum	Maximum		Minimum	Maximum
600	200	550	3,000	1,000	1,600
800	300	800	4,000	1,200	1,900
1,000	400	900	5,000	1,400	2,100
1,200	500	1,000	6,000	1,600	2,300
1,500	600	1,150	8,000	1,900	2,600
2,000	700	1,300			
2,500	850	1,500	10,000	2,100	2,800

SAFETY RULES TO BE OBSERVED WHEN WORKING ON FORGING PRESSES

The following safety rules and regulations must be strictly observed when working on forging presses:

1. Never use a forging press for work for which it is not designed.
2. Never attempt to remove scale, wipe the press or make any repairs while the press is working.
3. Never attempt to forge any work with wet dies, as hot water may injure workers standing nearby.
4. Never carry out any work on a press with faulty pressure-gauges.
5. Only the foreman is entitled to give orders to the press and crane operators; assistants may not issue any orders—they may only carry out the orders of their foreman.
6. Forge only in the centre of the dies. (Use only the centres of the dies for forging.)
7. Never attempt to forge metal at temperatures below those specified in the process chart.
8. When cutting with hot sets:
    a) Never place the hot set on the work in a slanting position;
    b) See that the head of the hot set is perfectly smooth;
    c) See that the extensions are in close contact with the entire surface of the head of the hot set.
9. Never use tapered sets, as they may fly off the work and injure workers standing nearby.
10. Never attempt to cut work near the edge of the bottom die.
11. See that the top and bottom dies are securely bolted in place.

12. When punching holes and when ejecting slugs from holes, see that the initial pressure is effected gradually.

13. If the punch sticks in the hole, never use the crane to pull it out.

FORGING OPERATIONS EXECUTED IN PRESSES

Hydraulic and steam-hydraulic presses are employed for producing heavy forgings weighing up to 100 tons and more, and from 150 to 2,500 mm in thickness. Forging operations in presses differ somewhat from forging operations in hammers—mainly because of the larger cross-sections of the forgings and stock. As a rule, ingots of polyhedral cross-section are used as stock for press forgings.

Drawing the Tail for the Chuck. The first operation in forging an ingot is that of drawing the ingot tail to fit the chuck. As a rule, the tail is drawn from the top discard side; more rarely—from the bottom discard side.

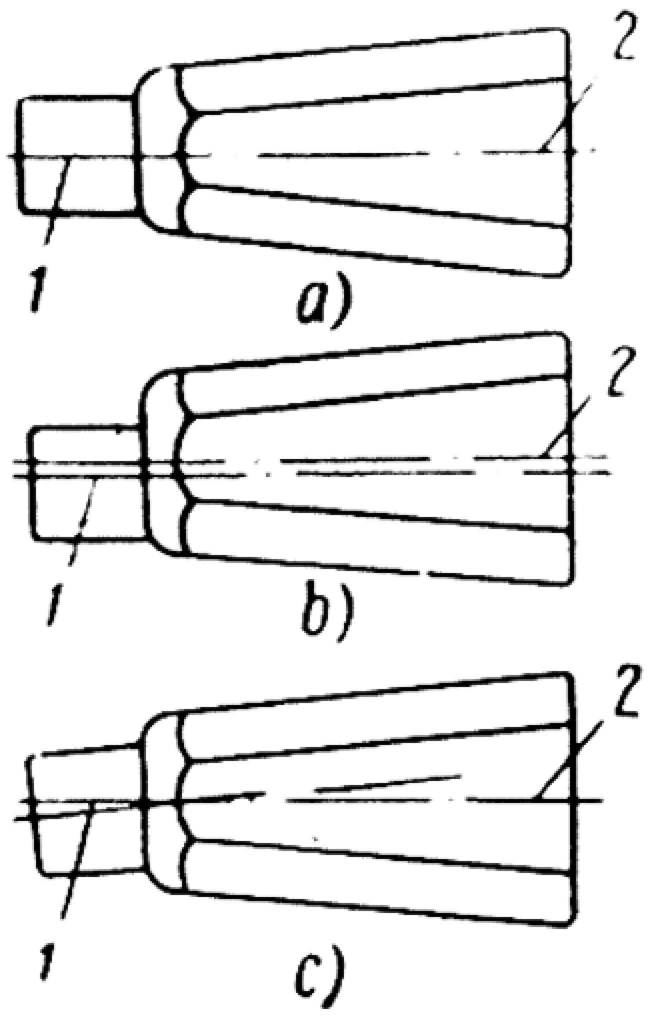


Fig. 233. Drawing the tail of ingot

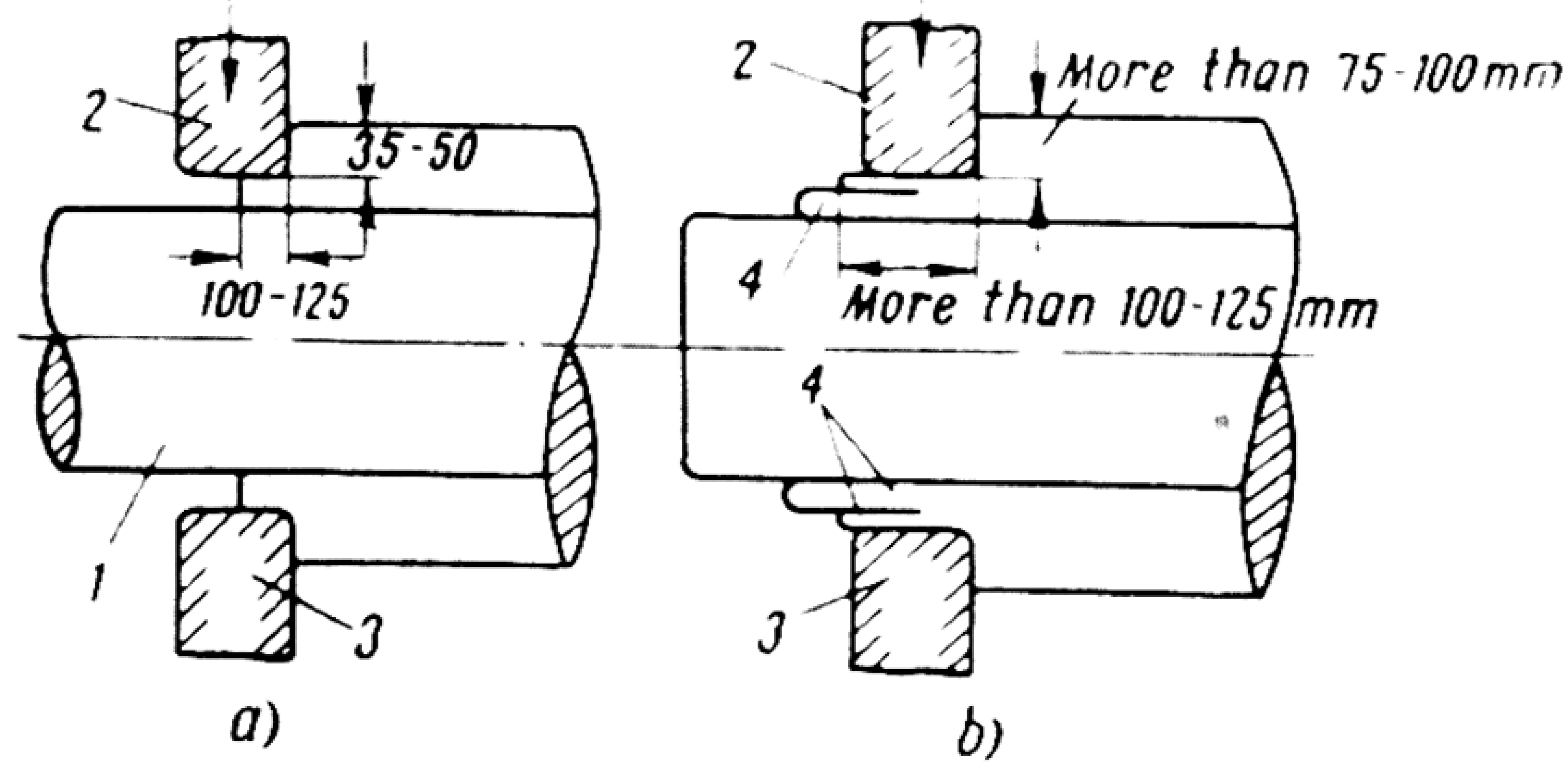


Fig. 234. Right (*a*) and wrong (*b*) way of reducing an ingot in a press:
1) stock ingot; 2) top die; 3) bottom die; 4) laps

In spite of its apparent simplicity, this is an exceedingly important and difficult operation, because the tail must be forged so that its axis *1* is in perfect alignment with axis *2* of the ingot (Fig. 233, *a*). Sometimes inexperienced blacksmiths draw the tail of an ingot as shown in Fig. 233, *b*, with axis *1* of the tail parallel to, but not in line with, axis *2* of the ingot; or as shown in Fig. 233, *c*, with the axis of tail *1* at a slight angle to the axis of ingot *2*. In both cases the forging must be corrected so that the axis of the tail is in strict alignment with that of the ingot.

Billeting the Ingot. The second operation when forging an ingot in a press is that of billeting, or rounding the edges of the ingot.

Ingots are billeted, in the first place, to make them perfectly round,

without any taper and, secondly, to increase the density of the metal at its edges. Ingots are best billeted in recessed dies.

When billeting an ingot, its reduction should not be too great, i. e., it should be worked under a light pressure of the dies, at a reduction rate of 35 to 50 mm per stroke. Greater reduction may cause surface cracks on the ingot. After the ingot has been completely reduced at the above rate, the pressure can be increased to a reduction of 75-100 mm per stroke, but the smaller the diameter of the ingot is, the less its reduction per stroke must be, and the length of the part of the ingot gripped by the dies must be always greater than the reduction per stroke of the press, as shown in Fig. 234, *a*. If, however, the length of the grip per stroke is smaller than the reduction of the ingot per stroke, laps may result (Fig. 234, *b*).

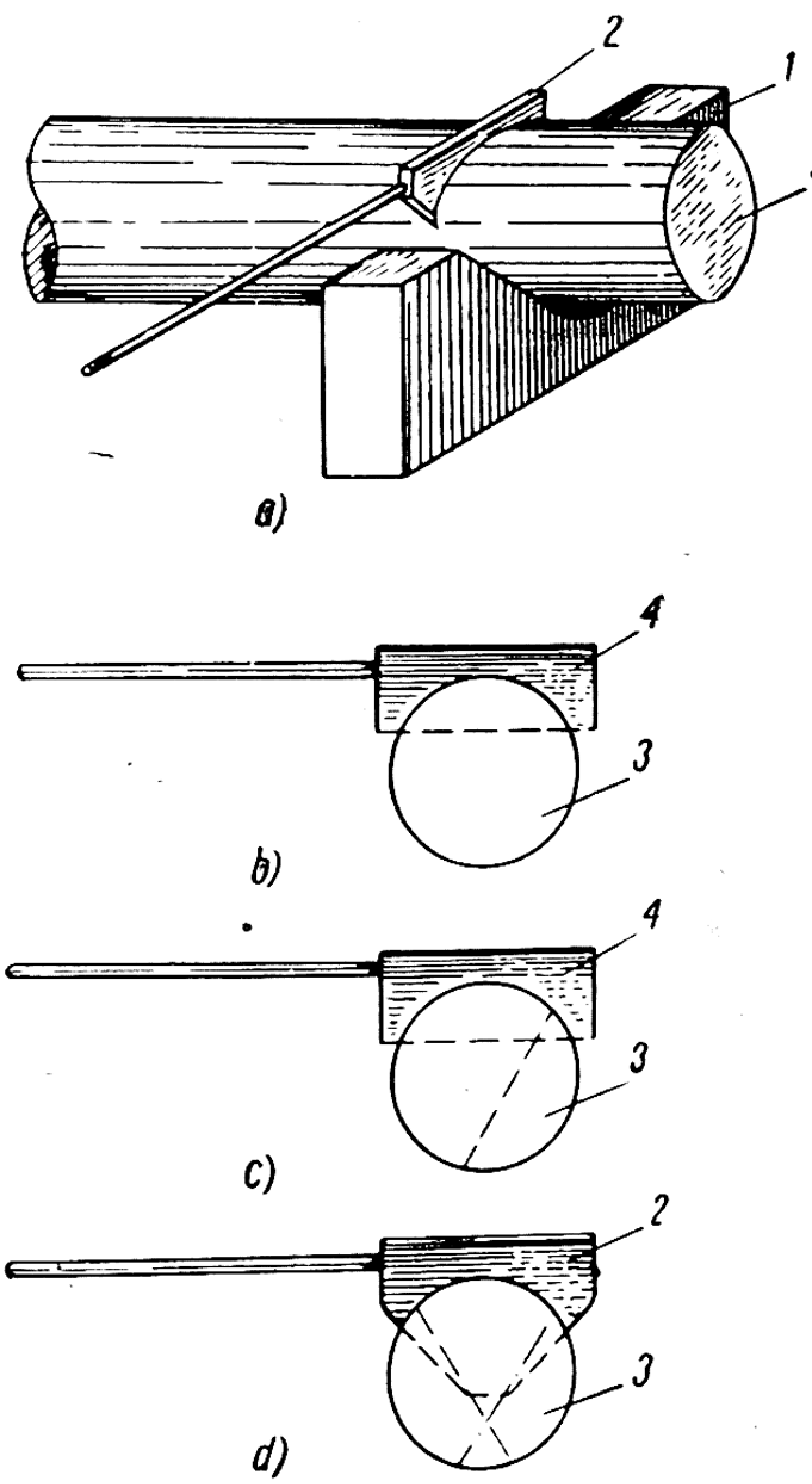


Fig. 235. Cutting round stock from three sides:

1) bottom die; 2) hot set for cutting stock in recessed die; 3) stock; 4) hot square cutter

Cutting. Cutting is performed both on recessed and flat bottom dies, recessed dies being employed for cutting round stock in the following manner.

The forging is placed on the bottom recessed die, so that the place to be cut is exactly in the centre of the die (Fig. 235, *a*). The first two cuts are performed with a straight hot set (Fig. 235, *b* and *c*), while the third, final cut, is performed with a shaped hot set (Fig. 235, *d*).

Plates and rectangular-shaped forgings must be cut on flat dies. Three methods of cutting forgings on flat dies are distinguished: a) cutting with a square cutter; b) cutting from two opposite sides, and c) cutting from all four sides. Cutting operations between flat dies are performed in presses in the same way as on hammers.

Upsetting an Ingot. Ingots are usually upset after being billeted. Comparatively light ingots are upset between flat dies (without plates). When making forgings from heavy ingots, top and bottom bolster plates must be used for the upsetting operation; the bottom plate, which is ring-shaped, is placed on the table of the press, and the top plate is placed over the ingot. Recesses in the upsetting plates facilitate the centring of the ingot in the press.

The ingot is upset in the following manner (Fig. 236). The billeted ingot, heated to the proper temperature, is placed on table *6* of the press so that its tail *2* enters the hole of bottom bolster plate *3*. Top plate *4*, which has a spherical recess, is placed over the head of the ingot. After the ingot, together with the bolster plates, has been installed on the press table, the ingot is slid into the press and centred under top die *5*; the slide is then lowered and gradually squeezes the ingot, upsetting it to the required diameter. After upsetting, the ingot is removed with the aid of a crane and secured in the chuck for further forging.

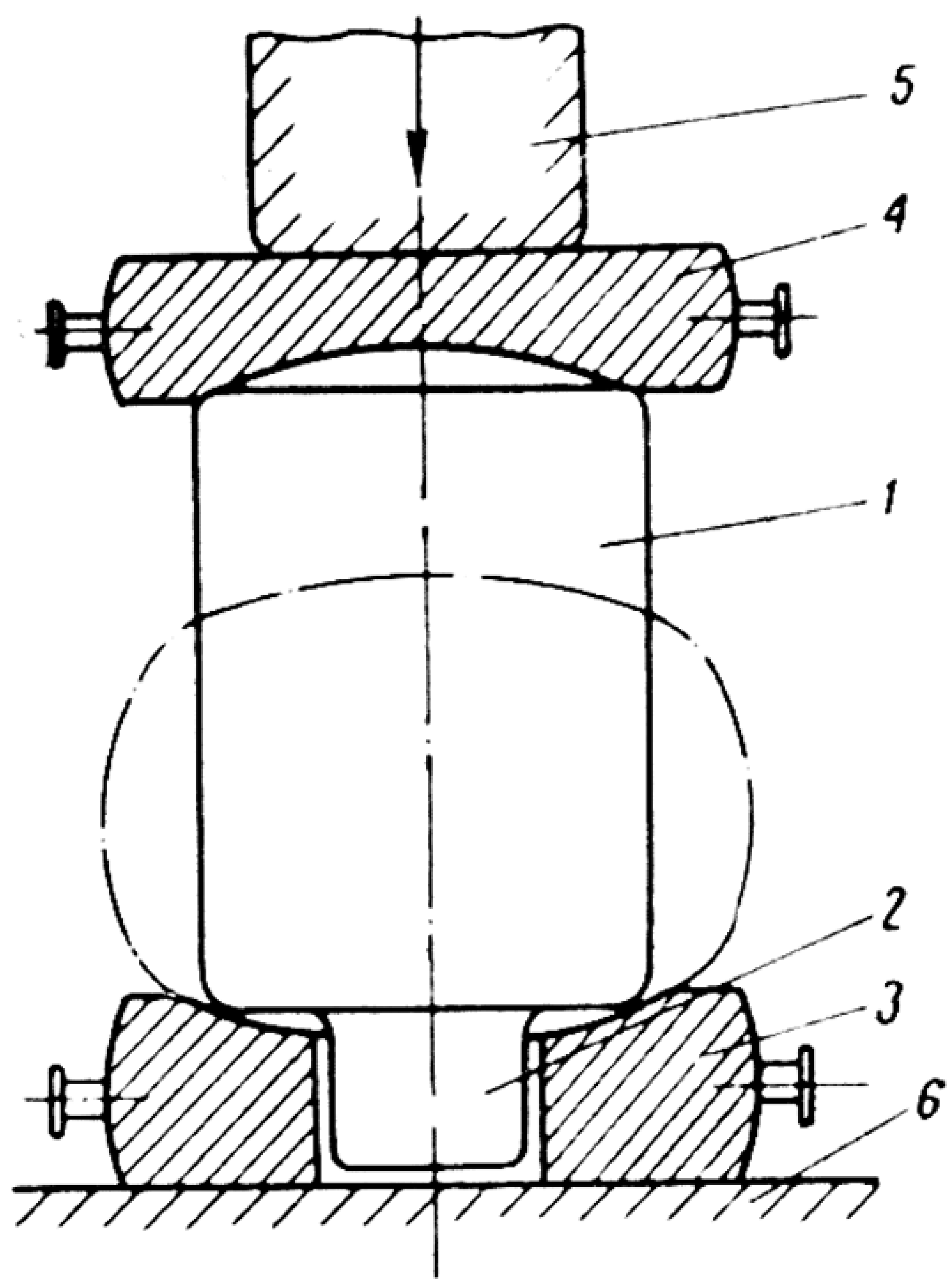


Fig. 236. Upsetting ingot in press

Installing the billeted ingot vertically in the press for upsetting, and installing it on the upsetting bolster plate are very arduous and important operations. Relatively light forgings can be installed vertically for upsetting with the aid of tongs, while special fixtures have to be employed for heavier forgings. Fig. 237 shows how a billet is installed vertically with a shackle and chain. Shackle *1* is placed under the ingot, which has been previously placed on support *2*. Crane chain *3* is lowered onto ingot *4* and passed round the shackle with the aid of long steel hooks. As the crane travels upwards, the chain tightens and holds the ingot in an upright position (Fig. 237, *b*).

Forgings are upturned directly in the press by manipulating the top die and the travelling table (Fig. 238). Top die *2* is pressed downwards on the edge of forging *4*, and table *1* moved in the direction indicated by the arrow in Fig. 238, *a*. The forging is then raised by the combined slow travel of the table and the pressure of the top die until it touches slide *3* (Fig. 238, *b*). Subsequent movement of the table will bring the forging into a vertical position in which it is held by the slide, as shown in Fig. 238, *c*.

Ingots with chucked tails are placed upright in presses with the aid of the special *upsetting ring* shown in Fig. 239 designed by P. Levandovsky and F. Tkachenko in the following way.

This upsetting ring comprises a hollow cylinder *1* with two levers *2* welded opposite each other and fitted with trunnions *3* and *4*. The crane chain is hooked onto trunnions *4*, and the ring, with the aid of the crane, brought under the chucked tail of the ingot; it is fitted on the tail, after which crane chain *7* is hooked onto trunnions *3*,

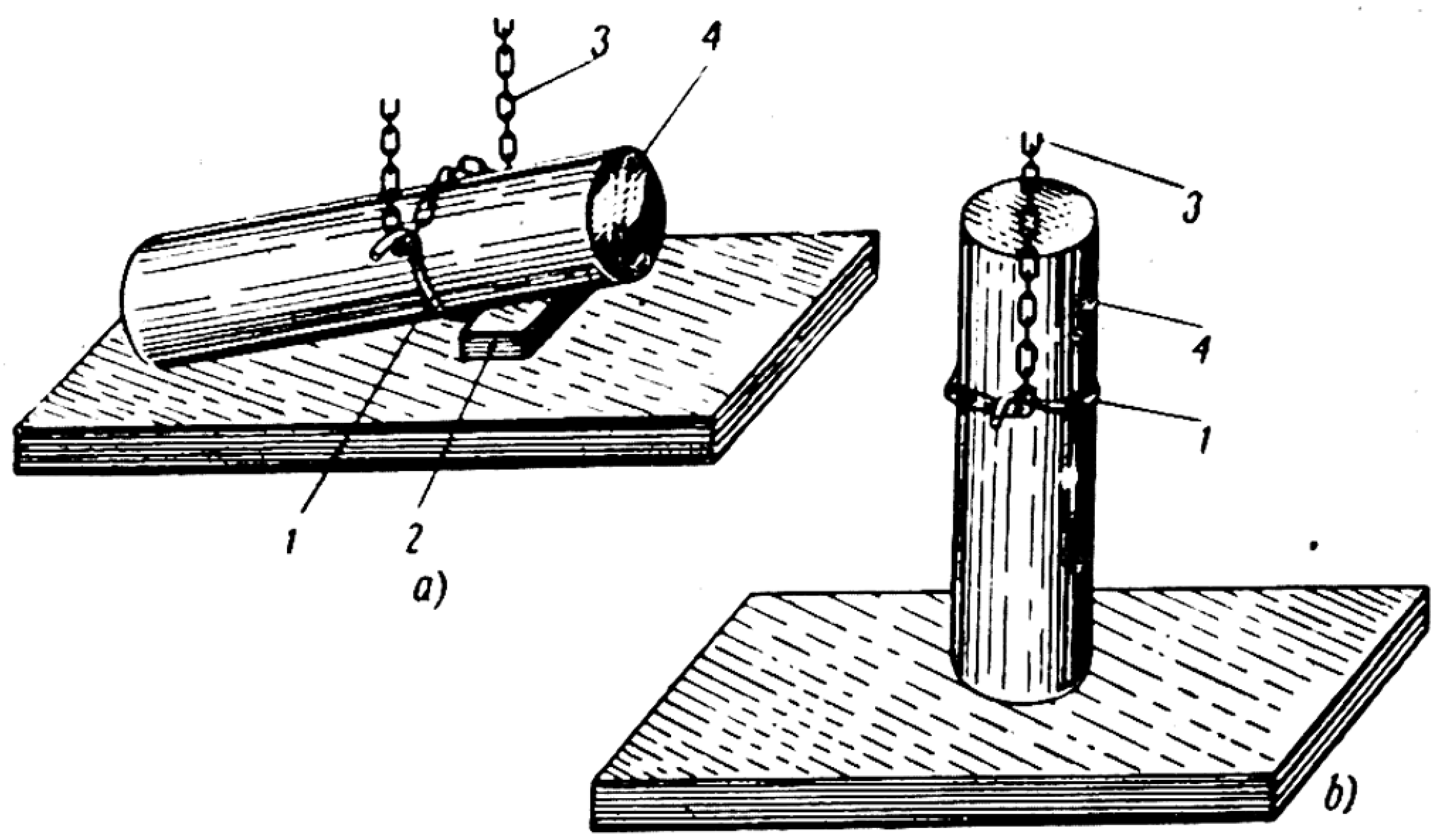


Fig. 237. Scheme of installing billeted (reduced) ingot in vertical position, using shackle and crane:

a) ingot before being raised in position; b) ingot placed in vertical position; 1) shackle; 2) insert plate; 3) chain; 4) ingot

and the ingot lifted together with the ring, the ingot taking an upright position as it is lifted. Together with the ring, the ingot is then placed on the travelling table of the press, and upset. After upsetting, the crane chain is again hooked to trunnions *3*, thereby turning the ingot into a horizontal position. The ingot is further squeezed between top and bottom dies *6* of the press (Fig. 239, *b*), during which operation the ring is withdrawn and a chuck inserted over the ingot tail for further drawing (reduction).

Punching. Two punching methods are employed, depending on the type of tool used: punching with a solid punch (Fig. 240) and with a hollow punch (Fig. 241).

When employing a solid punch, the metal will flow against the travel of the punch, i. e., the core of the stock being punched will spread along the inside surface of the cylinder.

When punching with a hollow punch, the metal is cut out, as it were. In this case, the shape of the resultant slug will be as shown in

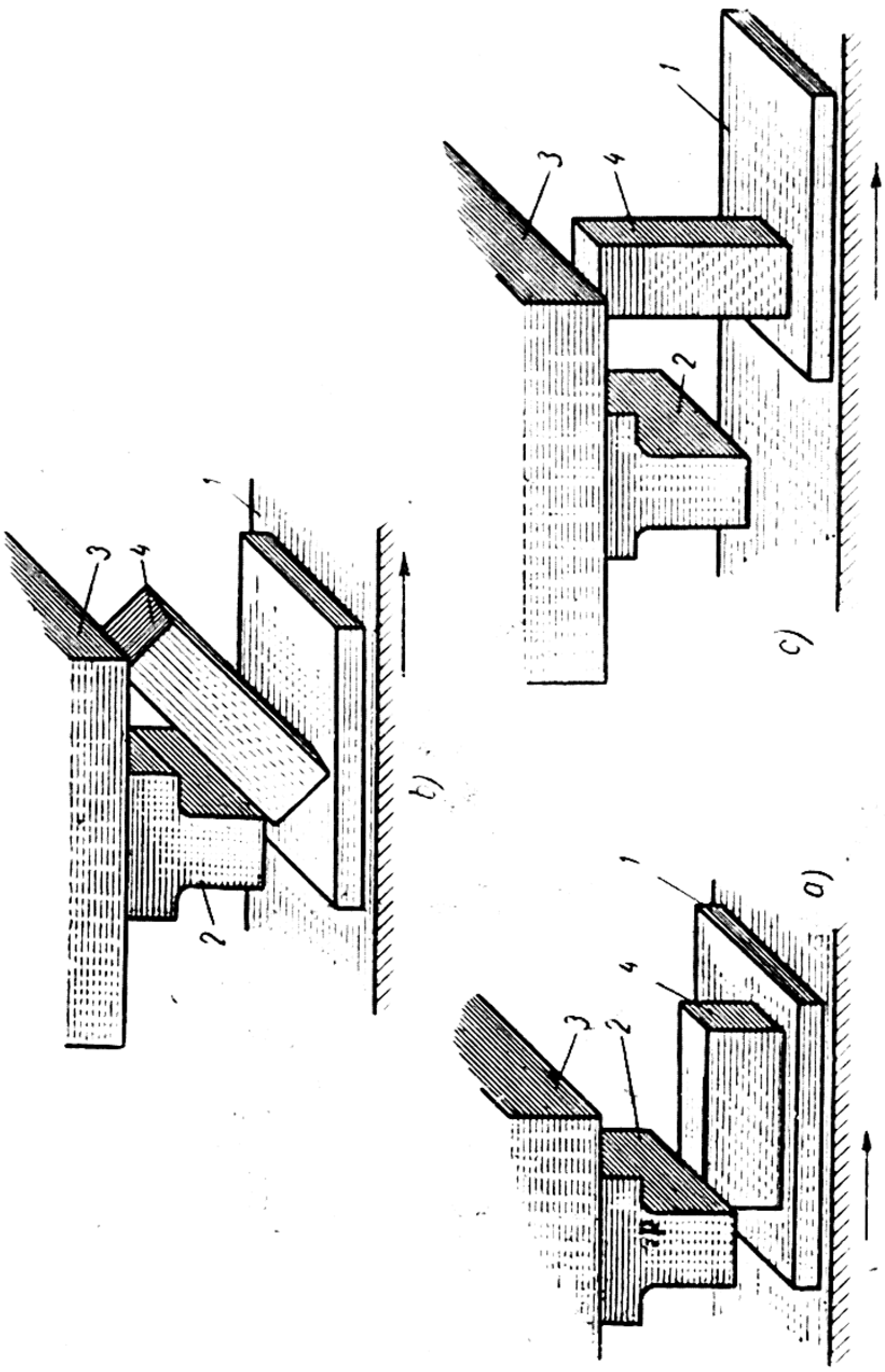


Fig. 238. Installing forging in vertical position with the aid of top die and movable table of press

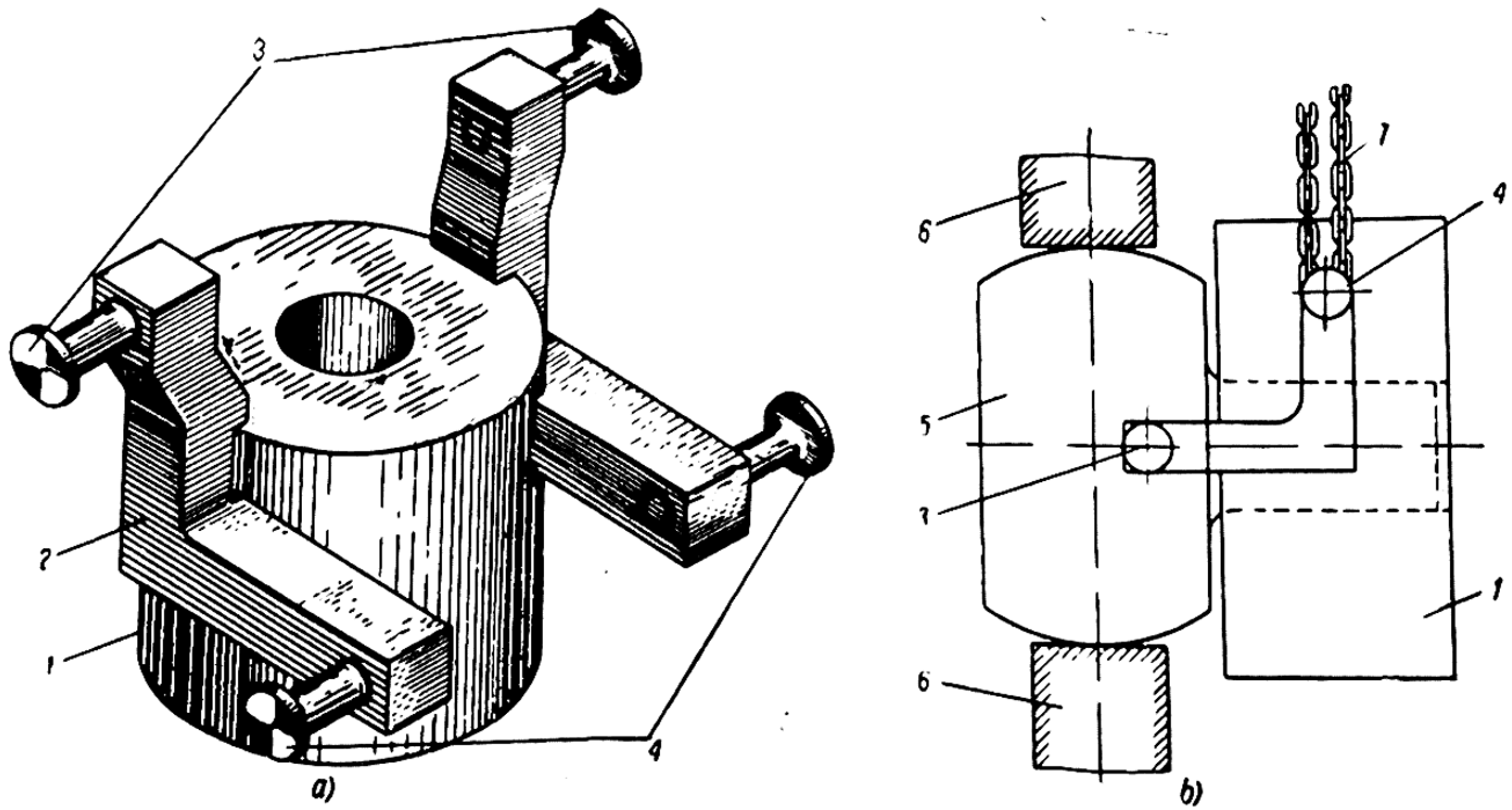


Fig. 239. Upsetting ingot with the aid of upsetting ring:
a) upsetting ring; b) removing ring from ingot after upsetting

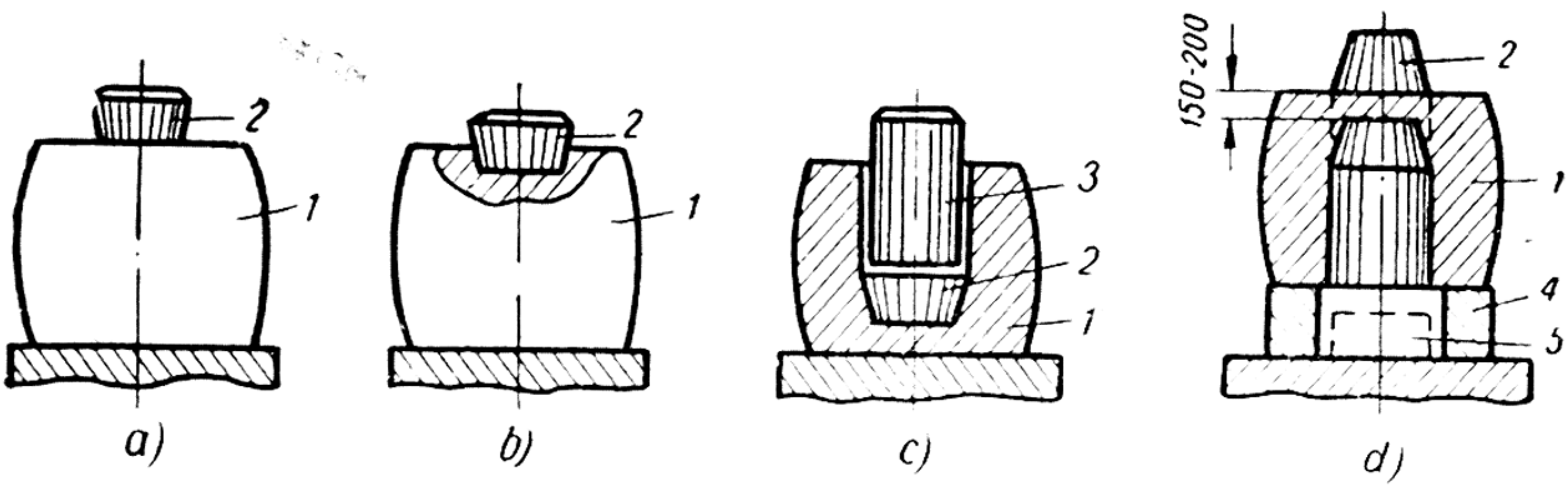


Fig. 240. Punching holes in heavy forgings with solid punches:
a, *b*, *c* and *d*—sequence of punching operations; 1) forging; 2) punch; 3) extension; 4) ring; 5) slug

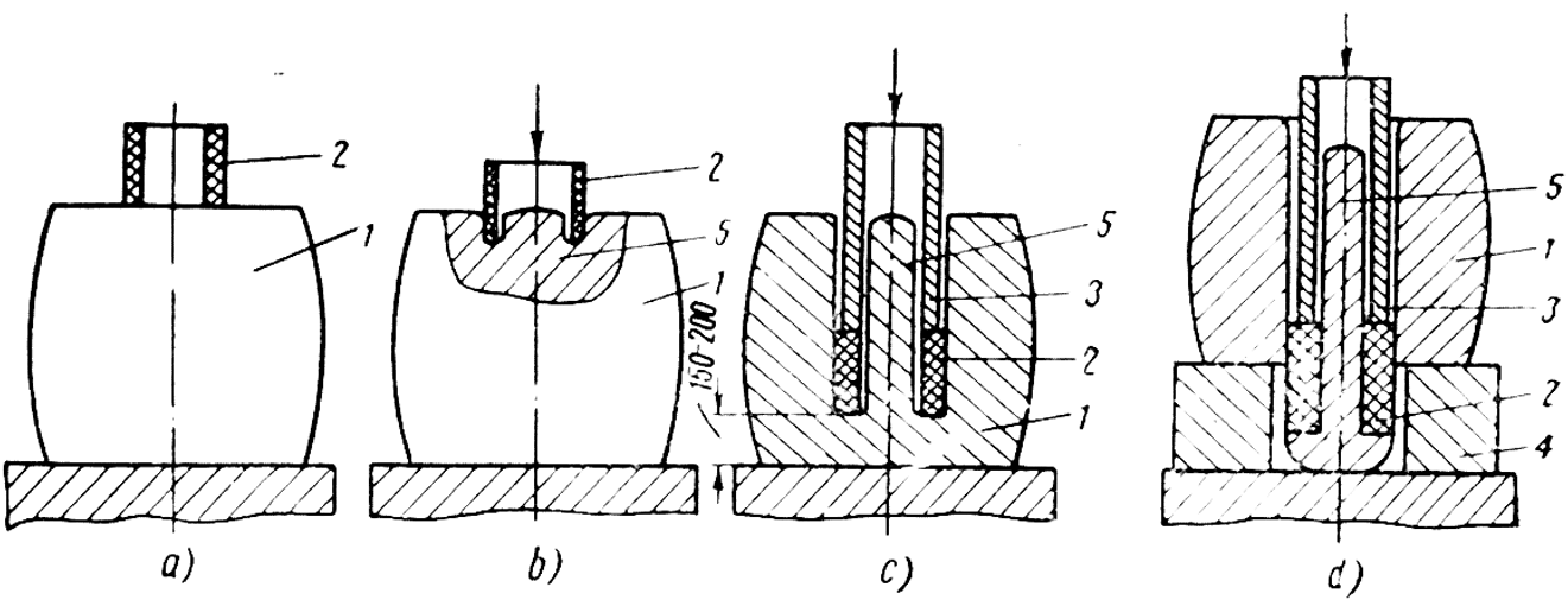


Fig. 241. Punching holes with hollow punches:
a, *b*, c and *d*—sequence of punching operations; 1) forging; 2) hollow punch; 3) extension; 4) ring; 5) slug

Fig. 242. The advantage of this method as compared with the first method is that it removes the shrinkage zone of the ingot (its core), thereby improving the mechanical properties of the forging.

The selection of the punching method depends on the grade of steel of the ingot and of the type of forging to be made. Generally, carbon-steel ingots are punched with solid punches; in this case, the punch is forced into the ingot to about 150-200 mm from its bottom surface, the punch and the pads are removed, the ingot is turned through 180°, and a piercing punch placed over the hole to finish the punching operation. The diameter of the

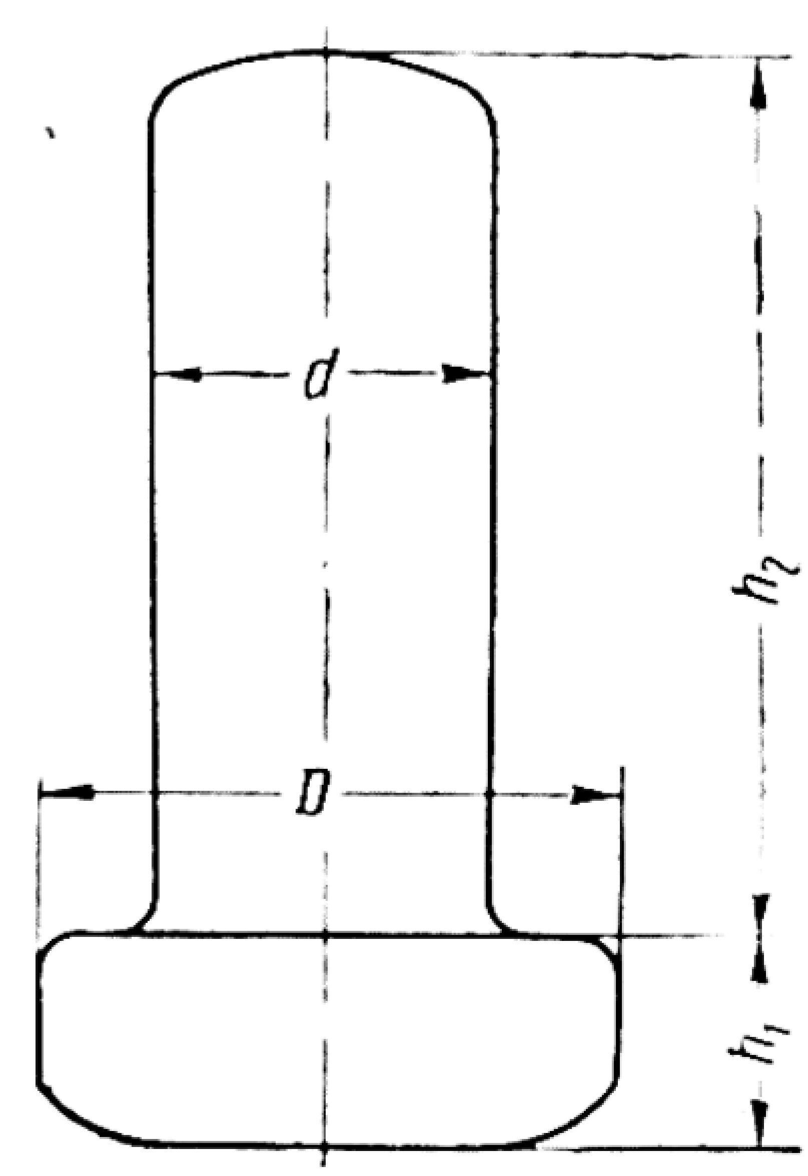


Fig. 242. Slug after punching hole with hollow punch

through, or finish, punch must be from 15 to 20 mm less than that of the first punch; this will ensure a better piercing of the remaining metal.

HANDLING MECHANISMS AND FIXTURES EMPLOYED IN PRESS FORGING

Tongs are the chief tools used in hammer forging. The blacksmith and his helpers with their tongs place the work on the anvil or die of the hammer in any required position.

Press forging is performed on heavy work, with heavy tools; for this reason hand operations during press forging are carried out with great difficulty and, at times, are impossible. For this reason, most of the stock handling operations (turning, installing the stock, etc.) are performed with the aid of overhead travelling cranes, manipulators, turning blocks and other fixtures, as, for instance, travelling tables for installing the bottom die of the forging press.

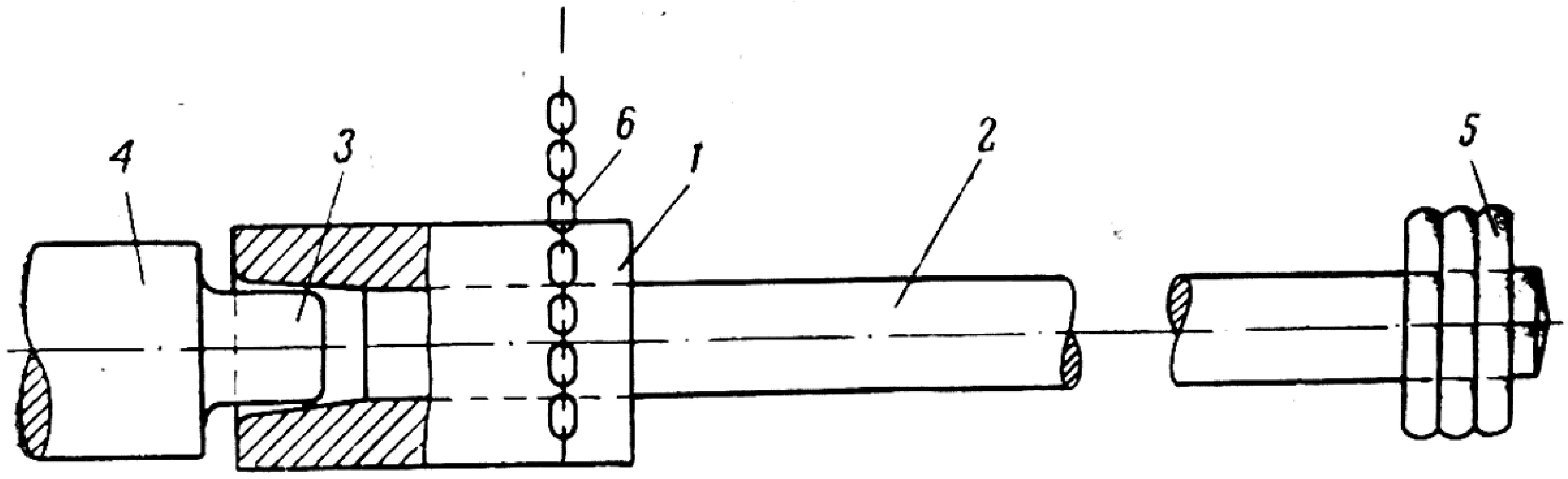


Fig. 243. Chuck employed for forging on presses:
1) chuck; 2) forged rod; 3) tail of ingot or forging; 4) ingot or forging; 5) counterweight; 6) turning block chain

Chucks. Chucks are used instead of ordinary blacksmith's tongs for press-forging operations. The chucks employed for press-forging operations differ from those employed for hammer forging. Press-forging chuck *1* (Fig. 243), is secured to forged rod *2*. The tail *3* of ingot or stock *4* is inserted into the chuck, and counterweight *5* attached to the opposite end of the chuck rod.

The chuck is used in the following manner. The first ingot press-forging operation, as has already been mentioned, is to draw out its chuck tail; this is performed without employing the chuck. Chain *6*, suspended from the crane, is passed over the ingot at its centre of gravity. The turning block turns the chain and the latter causes the ingot to rotate around its centre of gravity.

After the chuck tail has been forged, all further operations on the ingot are performed with the aid of the chuck; for this purpose, the

ingot is held between the dies of the press, and chain *6* of the turning block is passed over rod *2* of the chuck in such a position that, when lifted, the chuck, suspended from the crane, remains balanced. The overhead crane is then moved to the press and the chuck installed with its hole exactly opposite tail *3* of the ingot; when the crane travels "forward", the chuck moves over the ingot tail; to ensure that the chuck grips the ingot tail tightly, it is rotated

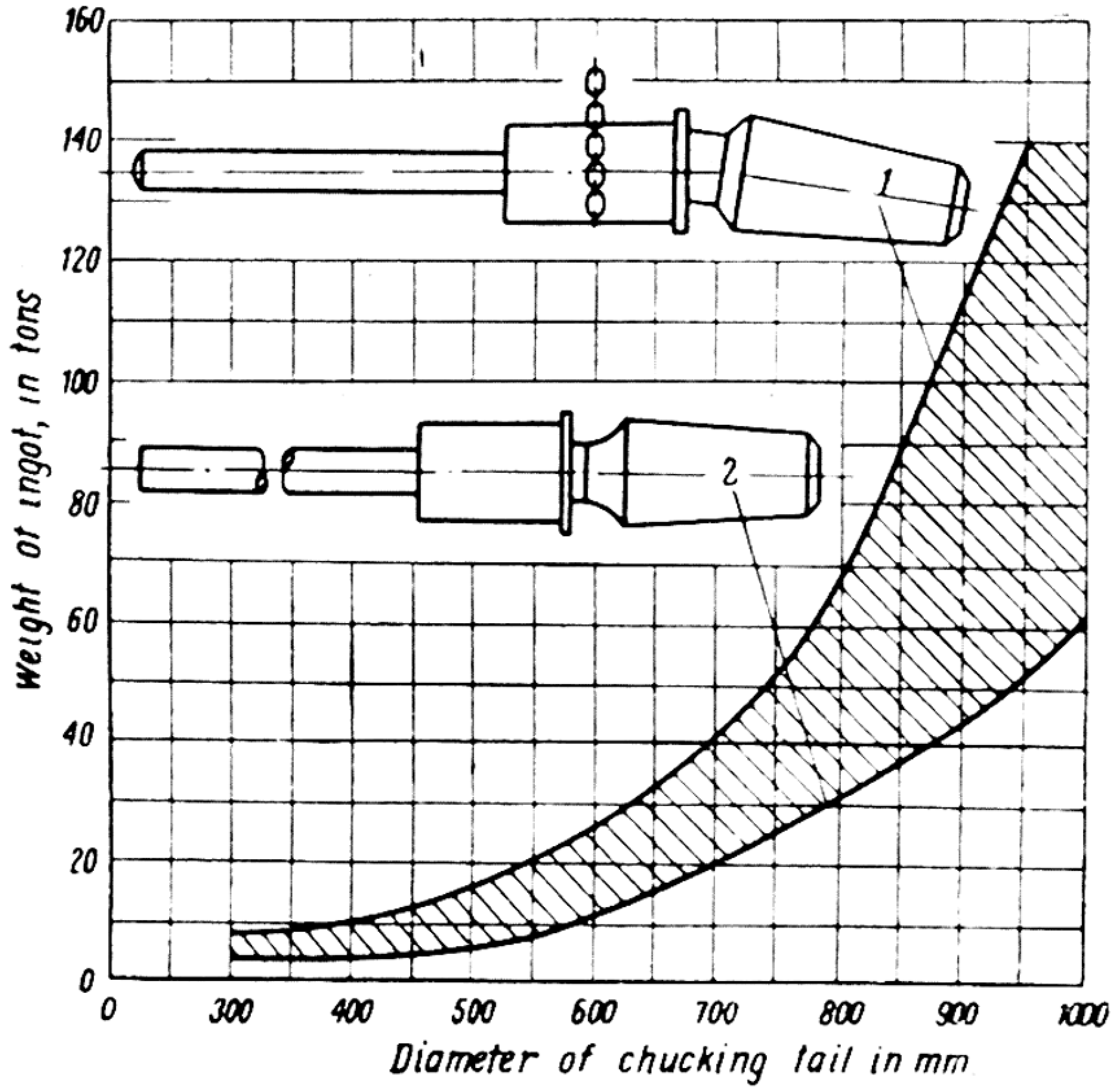


Fig. 244. Chart for selecting diameter of chucking tail to suit weight of ingot:

1) chucking tail of insufficient diameter (above upper curve bent in mandrel during forging); 2) chucking tail of proper diameter (between upper and lower curve)

round its axis by the turning block, causing it to thread itself, as it were, on to the tail of the ingot.

The diameter of the ingot tail depends on the weight of the ingot; if the diameter of the tail is too small it will bend during forging. Fig. 244 shows a *chart for selecting ingot tail diameters* corresponding to the weight of the ingot. If a diameter of ingot tail is selected according to the upper curve, the tail will bend, this will not happen if its diameter is selected according to the lower curve.

Example. It is required to select the diameter for the tail of an ingot weighing 50 tons. The point corresponding to 50 tons is found on the vertical scale in Fig. 244, and from this point a horizontal line is drawn until it intersects the curves. The point of intersection of

this horizontal line with the upper curve corresponds to a chuck diameter of 750 mm; and the point of intersection of the above-mentioned horizontal line with the lower curve will correspond to a chuck diameter of 950 mm. Therefore the required diameter of the ingot tail ranges from 750 to 950 mm. As chucks of 950 mm diameter are to be found in the shop, the ingot tail will be forged to a diameter approaching 950 mm.

The Turning Blocks. During both hammer and press forging the main movement to which a forging is subjected is that of axial rotation. This operation is effected with the aid of so-called turning blocks.

Turning blocks are fixtures designed for turning ingots and stock being forged. They are suspended from the hook of an overhead travelling crane, through the block of which is passed an endless chain, driven in the required direction by an electric motor. The turning block is controlled from the cabin of the overhead travelling crane.

The endless chain of the turning block is slung downwards, passed under the forging or the chuck in which the forging is held; when required, and at the blacksmith's order, the chain is turned in the necessary direction. Turning blocks are made with various lifting capacities ranging from 10 to 200 tons, to suit the capacity of the press.

EXAMPLES OF PRESS FORGING

Press forging has certain distinguishing features as compared with hammer forging. Below are described a few examples of making some of the most common forgings in a press.

Forging Shafts. Example 1. It is required to forge the shaft shown in Fig. 245, *a*; the dimensions of the shaft after finish machining are

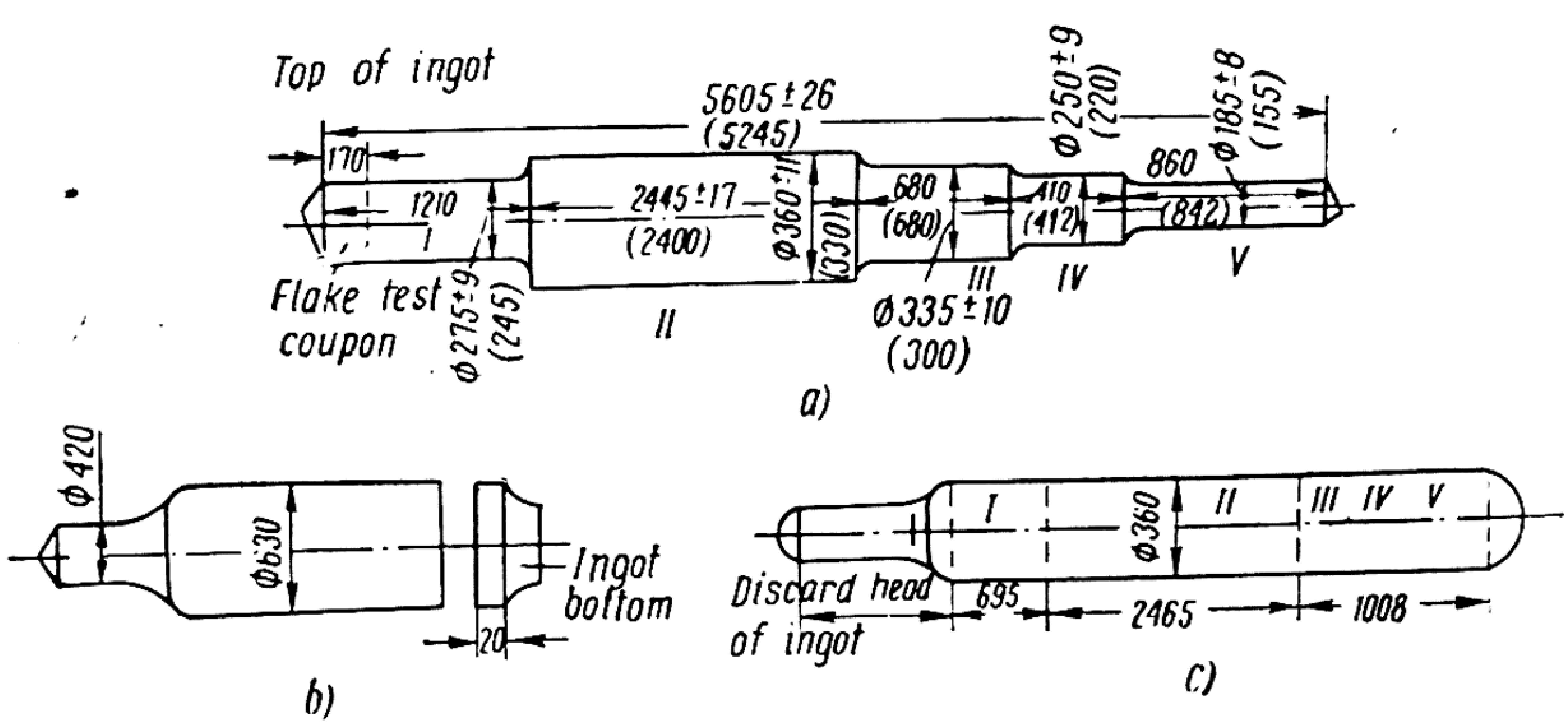


Fig. 245. Technological process of forging a shaft:
a) forging sketch of shaft; b, c) sketches of steps in forging shaft

given in brackets. The weight of the stock (ingot for one forging) is 5,120 kg; material—grade 40H steel.

First of all the *volume* and *weight of the shaft forging* are calculated. The shaft is divided into five sections:

1) The volume, V_1, of the section I will be:

$$V_1=\frac{\pi D_1^2}{4}l_1=\frac{3.14\times 27.5^2}{4}121=71{,}846 \text{ cm}^3;$$

2) The volume, V_2, of the section II will be:

$$V_2=\frac{\pi D_2^2}{4}l_2=\frac{3.14\times 36.0^2}{4}244.5=248{,}744 \text{ cm}^3;$$

3) The volume, V_3, of the section III will be:

$$V_3=\frac{\pi D_3^2}{4}l_3=\frac{3.14\times 33^2}{4}68.0=58{,}131 \text{ cm}^3;$$

4) The volume, V_4, of the section IV will be:

$$V_4=\frac{\pi D_4^2}{4}l_4=\frac{3.14\times 25^2}{4}41.0=20{,}127 \text{ cm}^3;$$

5) The volume, V_5, of the section V will be:

$$V_5=\frac{\pi D_5^2}{4}l_5=\frac{3.14\times 18.5^2}{4}86=23{,}091 \text{ cm}^3.$$

Thus the volume of the entire forging will be:

$$V_{forg}=71{,}846+248{,}744+58{,}131+20{,}127+23{,}091=421{,}939 \text{ cm}^3.$$

Its weight, W_{forg}, will be:

$$W_{forg}=V_{forg}\,g=\frac{421{,}939\times 7.85}{1{,}000}=3{,}312 \text{ kg}.$$

Knowing the weight and volume of the forging, the required volume and weight of the stock can be easily calculated. Considering the dimensions of the forging, it is clear that an ingot must be used as stock, and, moreover, that this ingot will produce one forging only. The volume of the ingot V_{ing} will therefore be:

$$V_{ing}=V_{forg}+V_{h.disc}+V_{crop}+V_{b.disc}+V_{sc} \text{ cm}^3.$$

The head and bottom discards are taken as 20 and 5 per cent respectively, and the loss due to scale as 3.5 per cent (the ingot will be heated twice). In this case, the waste loss from the head and bottom discards, plus scale loss will equal

$$20+5+3.5=28.5 \text{ per cent};$$

the permissible volume of metal for the forging, including end croppings, will be:

$$\eta = 100 - 28.5 = 71.5 \text{ per cent.}$$

The end croppings are calculated from the formula:

$$V_{crop} = 0.21\,D^3 \text{ cm}^3,$$

where D—diameter of cropped end. In this case it will be: cropping from left-hand end (section I), with $D = 275$ mm

$$V'_{crop} = 0.21 \times 27.5^3 = 4{,}368 \text{ cm}^3;$$

volume of right-hand end cropping (section V), with $D = 185$ mm

$$V''_{crop} = 0.21 \times 18.5^3 = 1{,}330 \text{ cm}^3.$$

Total volume of end croppings will therefore be:

$$V_{crop} = V'_{crop} + V''_{crop} = 4{,}368 + 1{,}330 = 5{,}698 \text{ cm}^3;$$

weight of croppings

$$W_{crop} = \frac{5{,}698 \times 7.85}{1{,}000} = 46 \text{ kg.}$$

The calculated weight of the ingot

$$W_{ing} = \frac{(W_{forg} + W_{crop})}{71{\cdot}5} \times 100 = \frac{(3{,}312 + 46) \times 100}{71{\cdot}5} = 4{,}696 \text{ kg.}$$

Ingots of this weight are not available in the U.S.S.R. Therefore from the table in Appendix 1, an ingot of the next standard weight of 5,120 kg is taken; this will give a yield of:

$$\eta_{yield} = \frac{3{,}312 \times 100}{5{,}120} = 64.7 \text{ per cent.}$$

Now the various *forging operations* and the intermediate forging dimensions can be specified. The first operation will be forging the chucking tail in a 1,200-ton press; the chuck is installed over the chucking tail and the edges of the ingot rounded to reduce the ingot to a diameter of 630 mm.

Operation 2: cropping the ingot bottom on the same press (Fig. 245, *b*).

Operation 3: forging the largest diameter (630 mm) of the shaft in recessed dies and grooving for sections I—II—III—IV—V (Fig. 245, *c*).

The length of each section of the forging must now be calculated:

a) The volume of metal V_1 required for section I, together with the cropping V'_{crop}, will be:

$$V_1 = 71{,}846 + 4{,}368 = 76{,}214 \text{ cm}^3;$$

the cross-sectional area of stock, A_{stock}, of diameter $D=360$ mm will be:

$$A_{stock}=\frac{\pi D^2}{4}=\frac{3.14\times 36^2}{4}=1{,}018^2\ \text{cm}^3;$$

the length of section I of the forging will be:

$$l_1=\frac{V_1}{A_{stock}}=\frac{76{,}214}{1{,}018}=74.8\ \text{cm};$$

b) The volume of metal, V_2, required for section II will be:

$$V_2=248{,}744\ \text{cm}^3;$$

its length, l_2, will be:

$$l_2=\frac{V_2}{A_{stock}}=\frac{248{,}744}{1{,}018}=244.3\ \text{cm};$$

c) The length of the forging for sections $\mathrm{III}+\mathrm{IV}+\mathrm{V}+l_{crop}$.
The volume of metal, V, for sections $\mathrm{III}+\mathrm{IV}+\mathrm{V}+\mathrm{V}''_{crop}$ will be:

$$V=58{,}131+20{,}127+23{,}091+1{,}330=102{,}679\ \text{cm}^3;$$

the corresponding length will be:

$$\frac{102{,}679}{1{,}018}\approx 100.8\ \text{cm}.$$

Operation 4: forging and finish forging shaft dimensions (Fig. 245, *a*) and cropping ends.

Forging temperature interval for operations 1, 2 and 3 will be 1,220°-700° C.

Example 2. Required to forge the stepped shaft shown in Fig. 246. The forging dimensions are given in Fig. 246, *a*, the dimensions in brackets being those of the shaft after finish machining. Weight of stock—5,120 kg (ingot for one forging). Material—grade 40H steel.

As in Example 1, the *weight* and *volume of the forging* are first calculated. The shaft is divided into eight sections and the volume of each section is calculated separately.

1) Volume of section I, V_1, will be:

$$V_1=\frac{\pi D_1^2\times l_1}{4}=\frac{3.14\times 28^2}{4}\times 45=27{,}675\ \text{cm}^3;$$

2) Volume of section II, V_2, will be:

$$V_2=\frac{\pi D_2^2\times l_2}{4}=\frac{3.14\times 30^2}{4}\times 10=7{,}068\ \text{cm}^3;$$

3) Volume of section III, V_3, will be:

$$V_3 = \frac{\pi D_3^2 \times l_3}{4} = \frac{3.14 \times 28^2}{4} 68 = 41{,}820 \text{ cm}^3;$$

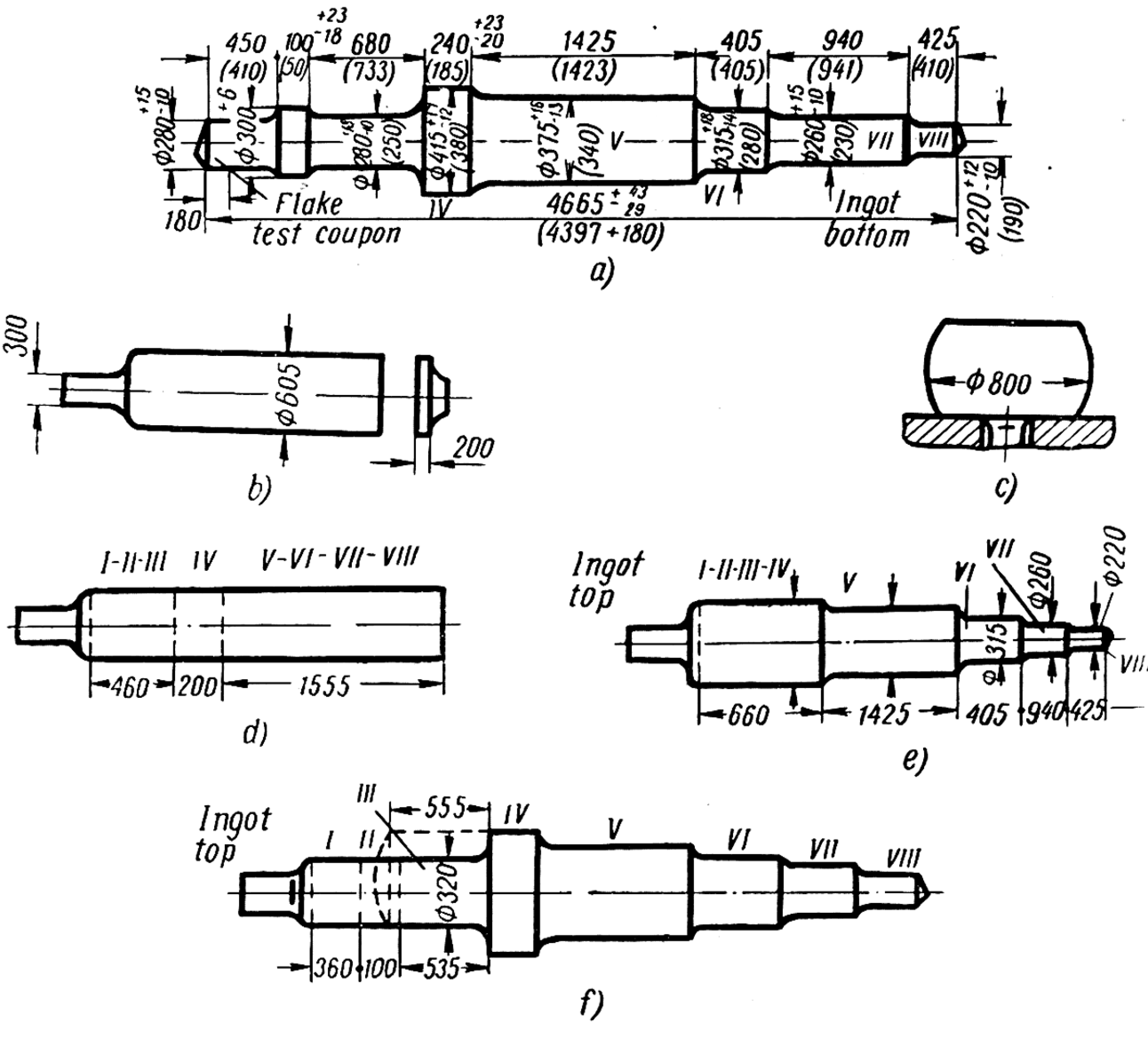


Fig. 246. Technological process of forging a stepped shaft:
a — forging drawing of shaft; *b*, *c*, *d*, *e*, and *f*—sketches of steps (passes) in forging shaft

4) Volume of section IV, V_4, will be:

$$V_4 = \frac{\pi D_4^2 \times l_4}{4} = \frac{3.14 \times 41.5^2}{4} 24 = 32{,}457 \text{ cm}^3;$$

5) Volume of section V, V_5, will be:

$$V_5 = \frac{\pi D_5^2 \times l_5}{4} = \frac{3.14 \times 37.5^2}{4} 142.5 = 157{,}386 \text{ cm}^3;$$

6) Volume of section VI, V_6, will be:

$$V_6 = \frac{\pi D_6^2 \times l_6}{4} = \frac{3.14 \times 31.5^2}{4} 40.5 = 31{,}590 \text{ cm}^3;$$

7) Volume of section VII, V_7, will be:

$$V_7 = \frac{\pi D_7^2 \times l_7}{4} = \frac{3.14 \times 26^2}{4} 94.0 = 49{,}820 \text{ cm}^3;$$

8) Volume of section VIII, V_8, will be:

$$V_8 = \frac{\pi D_8^2 \times l_8}{4} = \frac{3.14 \times 22^2}{4} \times 42.5 = 16{,}150 \text{ cm}^3.$$

The total volume of the shaft forging, V_{forg}, will be equal to the sum of the volumes of its sections:

$$V_{forg} = 27{,}675 + 7{,}068 + 41{,}820 + 32{,}457 + 157{,}386 + 31{,}590 + 49{,}820 + \\ + 16{,}150 = 363{,}966 \text{ cm}^3.$$

The weight of the forging, W_{forg}, will be:

$$W_{forg} = V_{forg}\, g = \frac{363{,}966 \times 7.85}{1{,}000} = 2{,}857 \text{ kg}.$$

The weight of the ingot, W_{ing}, required for the forging will be:

$$W_{ing} = W_{forg} + W_{h.disc} + W_{b.disc} + W_{sc} + W_{crop} \text{ kg}.$$

The waste is taken as:

$$W_{h.disc} = 20 \text{ per cent}; \quad W_{b.disc} = 10 \text{ per cent};$$
$$W_{sc} = 5 \text{ per cent}.$$

Three heats will be required for making the forging.

The losses due to the top and bottom discards and scale will therefore be:

$$20 + 10 + 5 = 35 \text{ per cent}.$$

The percentage of metal required for forging, together with the croppings will be:

$$\eta = 100 - 35 = 65 \text{ per cent}.$$

The volume of the end cropping is calculated from the formula:

$$V_{crop} = 0.21 D^3 \text{ cm}^3,$$

where D is the diameter of the cropped end. In this case:

a) The volume of the left-hand cropping V'_{crop} (from section I), will be:

$$V'_{crop} = 0.21 \times 28^3 = 0.21 \times 21.952 = 4.610 \text{ cm}^3;$$

b) The volume of right-hand cropping, V''_{crop} (from section VIII)

$$V_{crop}=0.21D^3=0.21\times 22^3=0.21\times 10{,}648=2{,}240\ \text{cm}^3.$$

The volume of waste due to croppings, V_{crop}, will therefore be:

$$V_{crop}=V'_{crop}+V''_{crop}=4{,}610+2{,}240=6{,}850\ \text{cm}^3.$$

Weight of waste due to croppings, W_{crop}, will be:

$$W_{crop}=V_{crop}\,g=\frac{6{,}850\times 7.85}{1{,}000}=54\ \text{kg}.$$

The calculated weight of the ingot, W_{ing}, will be:

$$W_{ing}=\frac{W_{forg}+W_{crop}}{\eta}\times 100=\frac{(2{,}857+54)\,100}{65}=4{,}478\ \text{kg}.$$

Ingots of this weight are not cast; from the table in Appendix 1, it is found that the ingot of the nearest standard size weighs 5,120 kg; hence, the yield from this ingot will be:

$$\eta=\frac{W_{forg}\times 100}{W_{ing}}=\frac{2{,}857\times 100}{5{,}120}\approx 56\ \text{per cent}.$$

Now the *forging operations* and the intermediate forging dimensions can be specified.

Operation 1: forge chucking tail of the ingot (Fig. 246, *b*).

According to the chart in Fig. 244, the diameter of the chucking tail should range from 300 to 350 mm. The diameter of the chucking tail is chosen to suit the chuck available in the shop, i. e., the chuck with a diameter of 300 mm, after which the chucking tail is forged. The chuck is installed on the tail of the ingot, and the edges of the ingot are rounded; its diameter is reduced to 605 mm, and the bottom discard is cropped off; this operation will be performed in recessed dies.

Operation 2 (Fig. 246, *c*): upsetting the ingot and reducing it in recessed dies. The method for ensuring the necessary reduction must now be decided on; as is known, when forging an ingot by the reduction method, and in the case the ingot will be drawn (reduced), the reduction factor must range between 2.5 and 3.5. In the case, a reduction factor of 3.5 is taken. To ensure this reduction, the cross-sectional area and diameter of the stock must be calculated.

The maximum diameter of the shaft forging, D_4, is 415 mm, which corresponds to a cross-sectional area:

$$A_4=\frac{\pi D_4^2}{4}=\frac{3.14\times 41.5^2}{4}=1{,}352\ \text{cm}^3.$$

To ensure the reduction factor of 3.5, the cross-sectional area of the initial stock, A_{stock}, must be not less than:

$$A_{stock} = A_4 \times 3.5 = 1{,}352 \times 3.5 \approx 4{,}732 \text{ cm}^2,$$

which corresponds to a stock diameter

$$D_{stock} = \sqrt{\frac{4A_{stock}}{3.14}} = \sqrt{\frac{4 \times 4{,}732}{3.14}} = 780 \text{ mm}.$$

The diameter of the stock, however (see Fig. 246, *b*), D_{stock}, is 605 mm. Therefore, to ensure the required reduction factor of 3.5, the ingot must be upset. For this reason, the second operation will be upsetting the ingot to a diameter of 800 mm, and reducing it in recessed dies to a diameter of 450-460 mm (Fig. 246, *c*).

The metal is then marked off into sections I+II+III; IV; V+VI+VII+VIII (Fig. 246, *d*) and sections V; VI; VII and VIII forged and finished (Fig. 246, *e*); the calculation of the metal required for each separate section is performed in the same way as in Example 1.

After the unforged section of the stock (from the chucking tail end) has been heated, sections I, II and III of the shaft are forged and finished (Fig. 246, *f*) and the entire forging is straightened.

All these operations are executed in a 1,200-ton forging press. Working tools used for the 1st operation: dies—flat top die and recessed bottom die; for the 2nd and 3rd operations—upsetting plates, flat top die and bottom flat and recessed dies; for the 4th and 5th operations — flat top die, recessed bottom die. Auxiliary tools: for the 1st operation—hot set; for the 4th and 5th operations — fuller and hot set.

Forging temperature intervals: for the 1st and 3rd operations — 1,220-800° C; for the 4th and 5th operations — 900-700° C.

Forging Tires (Rings). The following three fundamental problems have to be resolved when determining the technology necessary for forging tires: 1) the length of the ingot to be upset before punching the hole; 2) the diameter of the mandrel over which the tire will be rolled (it will be spread or rolled over a saddle); 3) the diameter of the hole before rolling, and the method of forming the hole.

Calculating the length of the stock to be upset before punching the hole is a most complicated and important problem. When rolling, i. e., spreading the tire, the metal spreads over the mandrel both along its circumference and along its width. Errors in calculating the upsetting height will lead to irremediable spoilage.

The tire will be spread (rolled) by narrow dies from 100 to 150 mm wide; the narrower the die, the better will the metal flow along the circumference, and the worse along the width of the tire. According to calculations made by B. Morozevich and N. Dorokhov, the height

of the stock before punching the hole for spreading (rolling) tires over 1,000 mm in diameter under dies from 100-150 mm wide, can be determined from the formula

$$h = H_0 \times B \text{ mm},$$

where h is the height of the stock in mm,
H_0 is the height of the forging in mm,
and B is a factor, given in Table 10.

Table 10

Table for Determining Factor *B*

Outside diameter of forging, mm	Height of forging, H_0, in mm										
	200	300	400	500	600	700	800	900	1,000	1,100	1,200
Up to 1,500	0.7	9.82	0.9	0.93	0.95	0.95	0.95	—	—	—	—
1,501-2,000	0.6	0.7	0.8	0.85	0.88	0.9	0.92	0.93	0.94	—	—
2,001-3,000	—	—	—	0.7	0.8	0.85	0.9	0.92	0.93	0.93	0.95

The diameter of the mandrel must be sufficient to prevent it from bending during the rolling of the tire. The mandrel acts as a bottom die during the rolling process; therefore, the smaller its diameter, the better (quicker) will the circumference of the tire be spread; thus, though mandrels for rolling should be of the smallest possible diameter, they should be sufficiently strong so as not to bend during the rolling (spreading) of the work.

Fig. 247 gives a chart for selecting the *diameter of mandrels*, depending on the length of the stock and its wall thickness. This chart only holds good when the tires are to be rolled under dies from 100 to 150 mm wide. The chart contains two curves—Curve I, for thick-walled forgings, and Curve II—for thin-walled forgings.

The diameter of the hole to be punched after the stock has been upset will depend on: a) the diameter of mandrel *2*; b) the conditions for removing the core of the ingot, i. e., the poor metal; and c) the available punches in stock.

Usually the diameter of the hole to be punched before rolling the tire must be at least twice the diameter of the mandrel. For responsible forgings, such as tires, the core of the ingot, i. e., all the metal containing various impurities and inclusions, must be removed. The core of an ingot can be removed with a hollow punch after upsetting.

In practice, holes up to 350-400 mm in diameter are usually punched in thick work with the aid of solid punches; holes over 400 mm in diameter are made with hollow punches.

Example. As an illustration, let us suppose it is required to forge the tire (ring) shown in Fig. 248, *a* from an ingot of grade 45 steel. The weight of the forging is 14,780 kg.

First of all, a *scale drawing of the finish machined tire*, in thin lines, is made and its basic dimensions written in.

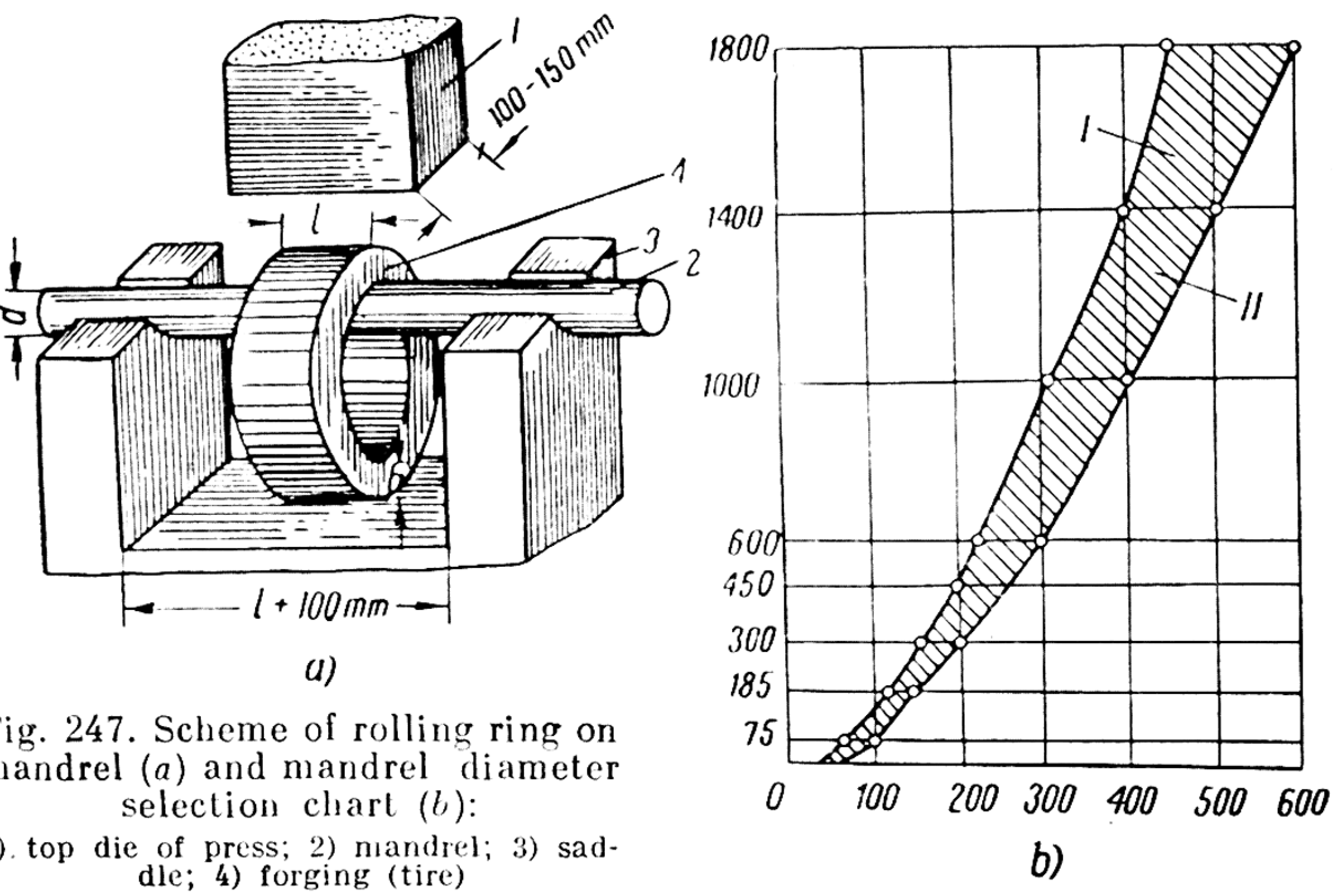


Fig. 247. Scheme of rolling ring on mandrel (*a*) and mandrel diameter selection chart (*b*):

1) top die of press; 2) mandrel; 3) saddle; 4) forging (tire)

From the tables in Appendix 3 and other appendixes, the necessary machining allowances and forging tolerances corresponding to the outside diameter D and height H of the tire are found. Then, in thick lines, the forging drawing of the tire is drawn round the drawing of the finished tire, and at the same time the forging dimensions and forging tolerances are written in (Fig. 248, *a*).

The *volume* and *weight of the forging* are then calculated. The volume of the forging, V_{forg}, will be:

$$V_{forg} = \left(\frac{\pi D^2 - \pi d^2}{4}\right) H = \left(\frac{3.14 \times 250^2 - 3.14 \times 136^2}{4}\right) 60 =$$
$$= (49{,}087 - 14{,}530) \times 60 = 2{,}073{,}600 \text{ cm}^3;$$

The weight of the forging, W_{forg}, will be:

$$W_{forg} = V_{forg} \times g = \frac{2{,}073{,}600 \times 7.85}{1{,}000} = 16{,}273 \text{ kg}.$$

The *weight of the ingot required for making the forging is now calculated.* The weight of this ingot, W_{ing}, will be:

$$W_{ing} = W_{forg} + W_{h.disc} + W_{b.disc} + W_{sc} + W_{sl} \text{ kg}.$$

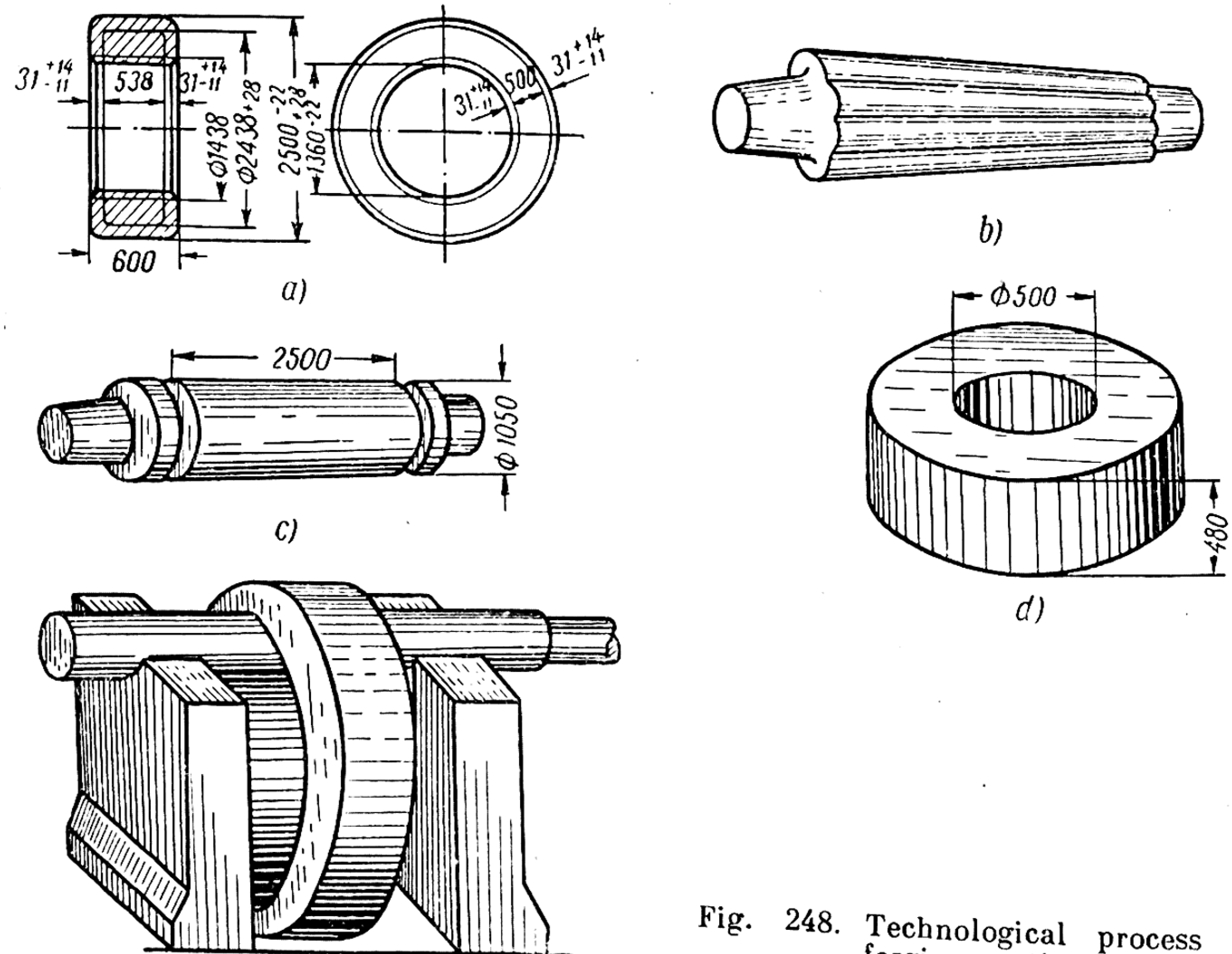


Fig. 248. Technological process of forging a tire:

a) forging drawing of tire; b, c, d and e) sketches of passes in forging tire

Weight of waste: of top discard—20 per cent; of bottom discard—5 per cent; of loss due to scale—3.5 per cent.

Total waste will be: $20+5+3.5=28.5$ per cent.

Yield η will be: $100-28.5=71.5$ per cent.

Weight of metal lost as slug. Before proceeding to calculate the weight of the metal lost as slug, we determine: a) the upsetting height of the stock before punching the hole; b) the diameter of the mandrel on which the work is to be spread, and c) the diameter of the hole and the method by which it is to be made. The tire is to be press forged. The width of the dies will be 150 mm. The height of our stock after upsetting and before punching is calculated from the formula:

$$H_1=H_0 B \text{ mm.}$$

H_0 (Fig. 248, *a*) is 600 mm; according to Table 10 Factor B for a forging of outside diameter $D=2{,}500$ mm, and height of forging $H_0=600$ mm, according to Table 10, will be 0.8; consequently, the height of the stock, H_1, before piercing must be:

$$H_1=600\times 0.8=480 \text{ mm.}$$

It is clear that, during the process of rolling the ring to diameter 2,500 mm, the forging will also increase its length (height) from 480 mm to the forging dimension $H_0=600$ mm.

The diameter of the mandrel for spreading the forging is determined from the chart in Fig. 247; for this, the point on the vertical scale corresponding to $H_0=600$ (height of our tire) is taken; from this point, a horizontal line is drawn to its intersection with the first curve (the tire is a thick-walled hollow forging). From the point of intersection of this horizontal line with the first curve *I*, a vertical line is dropped to intersect the horizontal scale, on which the mandrel diameters are given, the vertical line intersects this scale at a point corresponding to a minimum mandrel diameter of 250 mm.

For convenience in forging, the minimum diameter of the hole, before rolling, must be at least two diameters of the mandrel. Thus,

$$D_{hole}=2d_{mandrel}=2\times 250=500 \text{ mm.}$$

To remove the core of the ingot, it is decided to make the hole in the stock after upsetting with a hollow punch having an outside diameter O.D. $=500$ mm, and inside diameter I. D. $=250$ mm.

Thus, height H_1 of the ingot after upsetting $=480$ mm; the diameter of the hole to be punched, $D_{hole}=500$ mm. Now the volume and weight of the resultant slug must be calculated. After piercing with a hollow punch of 500 mm O. D. and 250 mm I. D., a slug of the shape shown in Fig. 242 will be formed.

Its dimensions will be:

$d=250$ mm (equal to the inside diameter of the hollow punch);

$D=500$ mm (equal to the outside diameter of the hollow punch);

$h_1=150$ mm, which is equal to the height of the unpunched section of the stock (see Fig. 242).

$h_2=1.1\ (H_1-h_1)=1.1\ (480-150)=360$ mm, i. e., the height of the stem of the slug will be equal to eleven-tenths of the difference between the height of the stock and the height of its non-punched section. Consequently, the volume of the slug, V_{sl}, when, as in this case, the hole is made with a hollow punch, will be:

$$V_{sl}=\left(\frac{\pi d^2\times h_2}{4}\right)+\left(\frac{\pi D^2\times h_1}{4}\right)=\left(\frac{3.14\times 25^2}{4}\times 36\right)+\left(\frac{3.14\times 50^2}{4}\times 15\right)=$$
$$=16{,}648+29{,}445=46{,}093\ \text{cm}^3,$$

the weight of the slug will be: $\dfrac{46{,}093\times 7.85}{1{,}000}=360$ kg.

The calculated weight of the ingot, W_{ing}, will thus be:

$$W_{ing}=\frac{(W_{forg}+W_{sl})\ 100}{\eta}=\frac{(16{,}273+360)\ 100}{71.5}=23{,}262\ \text{kg}.$$

Ingots of such weight are not available; referring to the table in Appendix 1, it is found that the ingot approximating to this weighs 26,328 kg, and this is selected. Now the different *forging operations* and the intermediate stock dimensions can be specified.

Operation 1: accepting ingot against certificate and melt analysis; forging chucking tail and cogging the ingot to 1,050 mm diameter (Fig. 248, *b*).

The diameter of the chucking tail is determined from the chart in Fig. 244. For ingots weighing 26 tons, this diameter will range from 600 to 750 mm. Since a chuck of 650 mm is in the shop, it is decided to forge the chucking tail to a diameter of 650 mm.

Operation 2: cropping the bottom discard of the ingot and cutting the stock to length (Fig. 248, *c*). The length of the stock is calculated. The cross-sectional area of a stock of $D=1{,}050$ mm, A_{stock} will be:

$$A_{stock}=\frac{\pi D^2}{4}=\frac{3.14\times 105^2}{4}=8{,}660\ \text{cm}^2.$$

The weight of the metal required for the forging, slug and loss due to scale will be:

$$W=W_{forg}+W_{sl}+W_{sc}.$$

Loss of metal due to scale will be equal to:

$$W_s=(W_{forg}+W_{sl})\times 0.035=(16{,}273+360)\ 0.035=582\ \text{kg},$$

therefore, the weight of the stock will be:

$$W = 16{,}273 + 360 + 582 = 17{,}215 \text{ kg}.$$

The volume of metal required for the forging, slug and scale loss, will be:

$$V = \frac{G}{g} = \frac{17{,}215 \times 1{,}000}{7.85} = 2.193{,}000 \text{ cm}^3.$$

The required length of stock l will therefore be:

$$l = \frac{V_{stock}}{A_{stock}} = \frac{2.193{,}000}{8{,}660} = 250 \text{ cm}.$$

Ratio of height to diameter of stock will be:

$$\frac{2{,}500}{1{,}050} = 2.38,$$

i. e., within the limits which ensure upsetting the stock without its buckling.

Operation 3: upsetting stock to height of 480 mm, and piercing a 500 mm diameter hole with a hollow punch (Fig. 248, *d*).

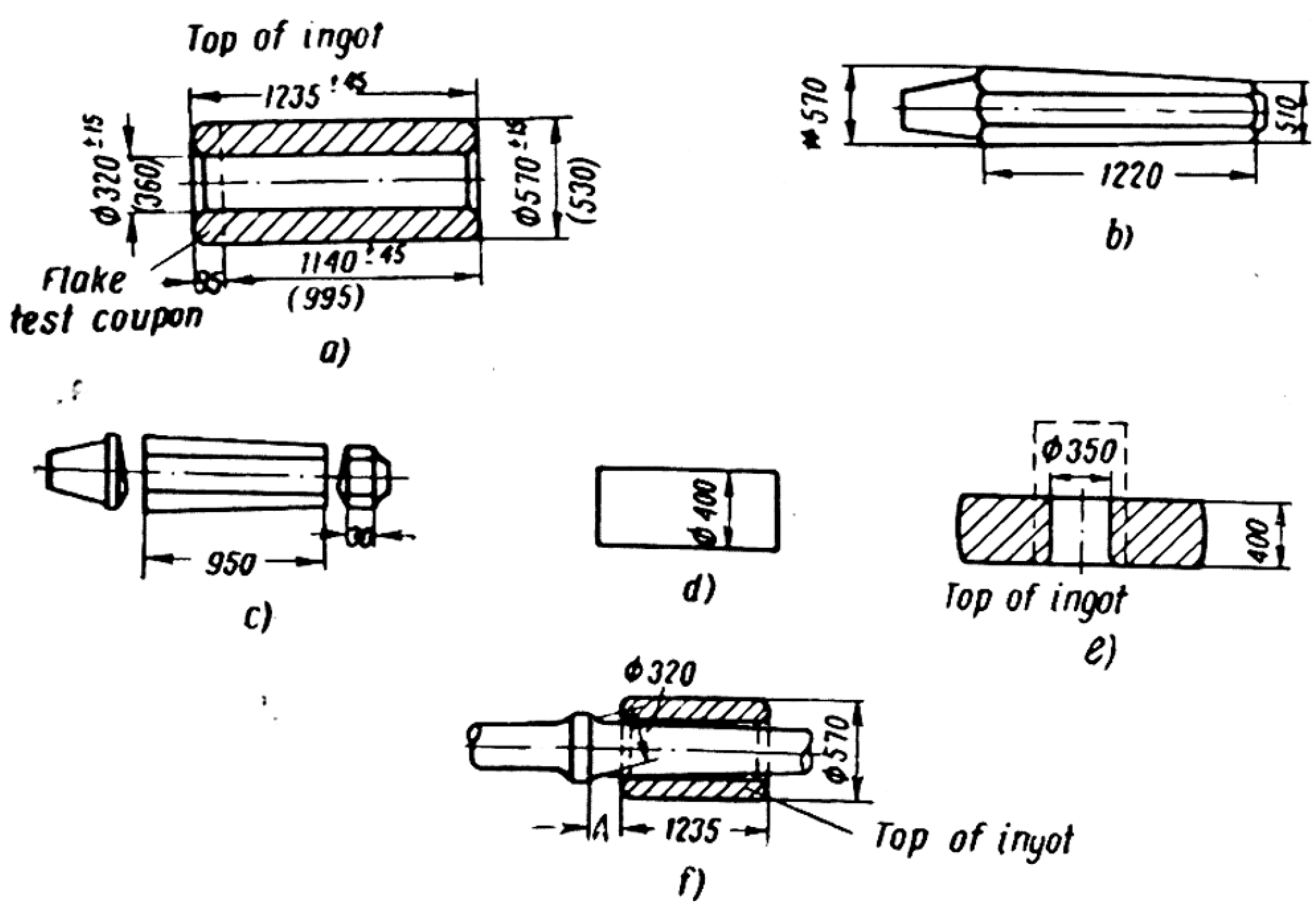


Fig. 249. Technological process of forging a hollow ring:
a) forging drawing of hollow ring; b, c, d, e and f) sketches of passes in forging

Operation 4: rolling (spreading) stock on a 250 mm diameter mandrel to forging dimensions (Fig. 248, *e*).

All these operations will be performed in a 2,000-ton forging press. The following working tools will be used: for the 1st and 2nd operations—flat top die and bottom recessed die; for the 3rd opera-

tion—flat top plate and flat bottom plate; for the 4th operation—narrow top tie and saddle. Auxiliary tools: for the 1st and 2nd operations—hot set; for the 3rd operation—500 mm diameter hollow punch, and 600 mm diameter ring; for the 4th operation—250 mm diameter mandrel.

Forging temperature interval 1200-750° C.

Forging Hollow Forgings. Hollow forgings, as distinguished from ring forgings, are made by drawing-out over mandrels. Fig. 249 , *a* illustrates the *technological process* of forging a hollow ring.

The weight of the stock for this ring is 3,000 kg (an ingot for one forging only); weight of forging—1,700 kg. Material grade 40X steel. The ring will be forged on a 2,000-ton press. Tools required: working tools for the 1st and 4th operations—flat top and bottom dies, upsetting plate; for the 5th operation—flat top die, recessed bottom die, marking out tools and a marking punch. Auxiliary tools: for the 1st and 4th operations—hot sets, 350 mm diameter punch; for the 5th operation—320 mm diameter hollow mandrel, sledge-hammer.

Forging temperature interval: for the 1st and 4th operations—1220-800° C; for the 5th operation—1220-750° C.

In this case, the chief and most important forging operation will be drawing (Fig. 249, *f*). Forgings of this type are drawn over a mandrel; during this operation, they increase in length as a result of the reduction in their outside diameter and wall thickness.

Drawing on a mandrel is effected between a flat top die and a recessed bottom die, or between recessed top and bottom dies. After upsetting, the stock is punched to take the mandrel (Fig. 249, *e*), the diameter of the hole being about 30-50 mm greater than the inside diameter of the forging.

Hollow forgings are drawn over *hollow mandrels* with tapered working parts, which facilitate their withdrawal from the forging on the completion of the drawing operation. The working surfaces of such mandrels must have a high finish. During the drawing operation, the mandrel must be cooled by a continuous stream of cold water delivered to the inside of the mandrel. The diameter of the mandrel must be equal to the inside diameter of the hollow forging. Fig. 250 illustrates a *hollow tapered mandrel*.

To ensure a sound hollow forging, the following fundamental rules should be observed when drawing the forging on the mandrel:

1) Before drawing, the metal must be properly and uniformly heated to the required forging temperature;

2) Drawing on a mandrel must be performed in the following sequence:

Insert the mandrel inside the work so as to leave a clearance *A* (Fig. 249, *f*) between the work and the shoulder of the mandrel;

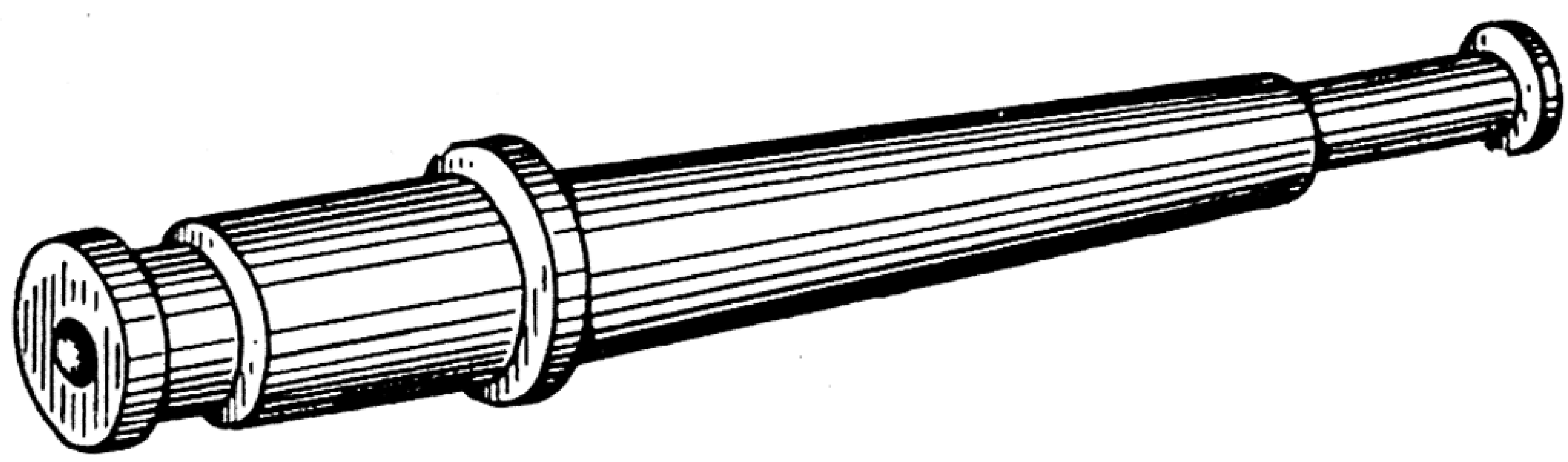


Fig. 250. Taper mandrel

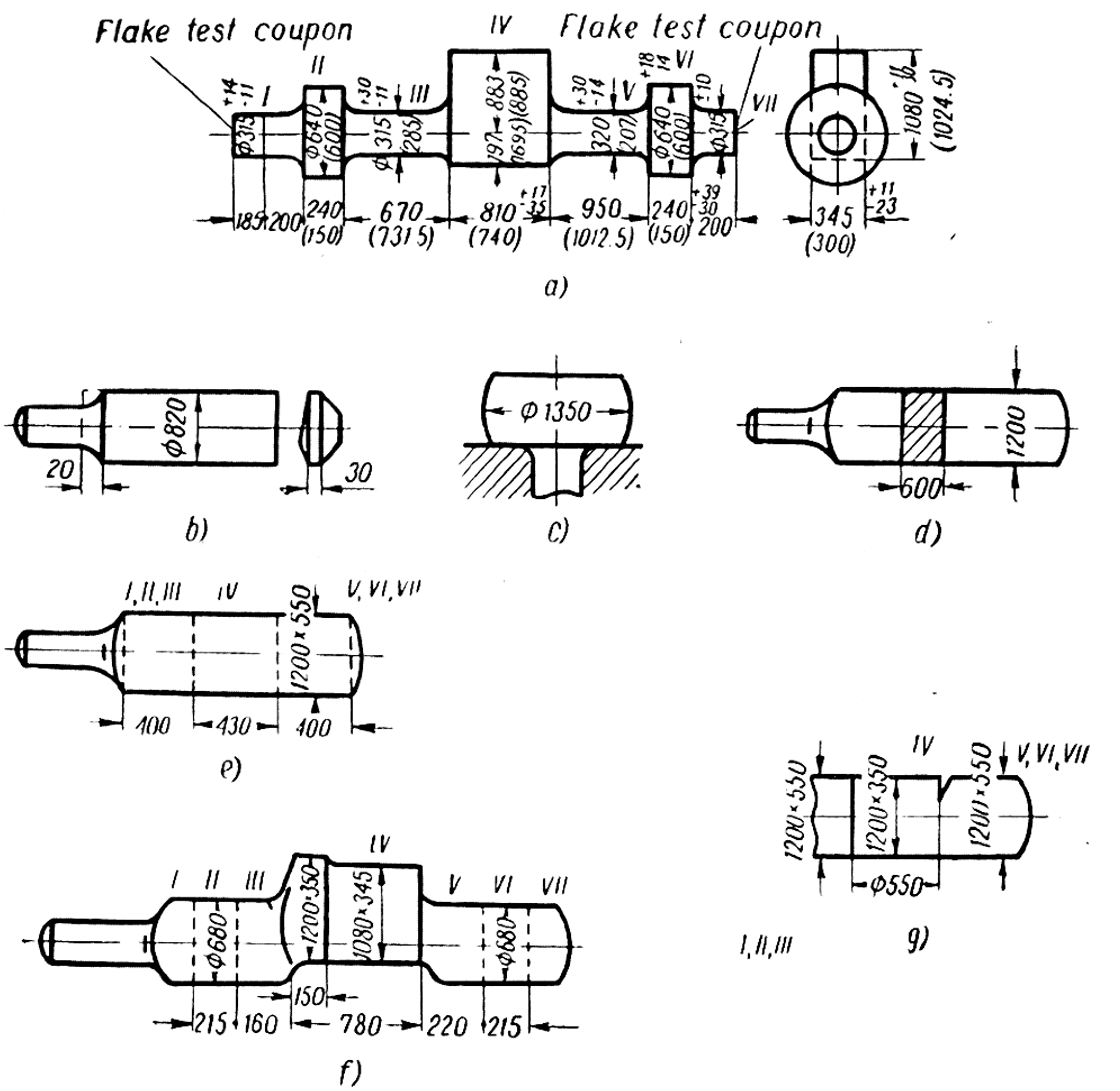


Fig. 251. Technological process for forging a crankshaft:
a) forging drawing of shaft; b, c, d, e, f and g) sketches of passes for forging crankshaft

then draw out the left-hand end of the work, proceeding from right to left, i. e., towards the shoulder of the mandrel, and always in the same direction. In doing so, the metal will be forced against the shoulder of the mandrel. Then draw out the right-hand taper side and the central section of the work. This sequence of forging operations will ensure a high-quality forging which can be easily removed from the mandrel.

Forging a Crankshaft. Crankshafts are complicated and important forgings. The method of making a crankshaft will depend on its design: on the dimensions, numbers of journals and their relative positions, whether the crankshaft is to be flanged or not, on the grade of material, etc. Fig. 251 shows the forging sketch of a crankshaft to be made according to the *technological process* given in Fig. 251*a*, *b*, *c*, *d*, *e*, *f* and *g*.

This technological process incorporates the following operations:

1) Forging the chucking tail, rounding (cogging) the ingot to 820 mm diameter and cropping off the ingot bottom (Fig. 251, *b*);

2) Upsetting the ingot to 1,350 mm diameter (Fig. 251, *c*);

3) Forging on 1,200 × 600 mm plate (see Fig. 251, *d*);

4) Forging to 1,200 × 550 mm, grooving for sections according to sketch (Fig. 251, *e*);

5) Forging to 1,200 × 350 mm at section IV, grooving metal for sections V-VI and VII (Fig. 251, *f*);

6) Grooving for sections I, II and III, forging and finishing section IV, grooving for section V, and forming sections V, VI and VII (Fig. 251, *g*);

7) Grooving for section III, forging and finishing sections III, II and I; straightening the forging, and cutting off excess metal (Fig. 251, *g*).

The weight of the stock is 10,300 kg; the weight of the forging is 5,200 kg. Material—grade 35 steel. All operations are performed in a 3,000-ton press. Tools required: working tools for all operations—flat top dies and flat and recessed bottom dies; for the 3rd, 4th and 5th operations—flat top die, recessed bottom die and bottom plate; auxiliary tools: for the 1st and 2nd operations—upsetting plates, hot sets; for the 3rd, 4th, 5th, 6th and 7th operations—side sets, hot sets and square cutters.

Forging temperature intervals: for the 1st and 2nd operations—1220-800° C; for the 3rd and 5th operations—1220-750° C; for the 6th and 7th operations—950-730° C.

CHAPTER XII

AUTOMATIC FORGING AND STAMPING MACHINES

GENERAL INFORMATION ON AUTOMATIC FORGING AND STAMPING MACHINES

Automatic forging and stamping machines are widely employed in nearly all branches of the machine-building industry, particularly in automobile, tractor, aircraft and other plants. These automatic machines are employed for the mass production of nuts, bolts, rivets, railway track spikes, wood screws, rollers, ball-bearing balls, and other components. These components can be produced by the hot, cold or semi-hot (i. e., with stock at temperatures ranging from 600 to 700° C) processes. The cold process is employed for making components from gauged rods up to 25 mm in diameter, and the hot process—for making components from bars up to 50 mm in diameter.

The method employed for the production of machine components on automatic forging machines depends on the dimensions, shape and required precision of the parts. The greatest precision is attained by cold stamping parts in cold heading automatic machines. The precision of work produced in these machines approximates that of work produced on lathes.

The productivity of automatic forging and stamping machines is ten or even a hundred times greater than that of automatic machine-tools. In addition to their high productivity, automatic forging machines ensure a great economy of metal, particularly when producing parts by the cold heading process.

Modern automatic machines incorporate a considerable number of complicated and precise mechanisms which unless properly handled are liable to break very quickly. Therefore, the productivity, service life and quality of production of automatic machines depend on the strict observance of all the operating and maintenance rules. Particular care should be paid to proper lubrication of all the mechanisms of automatic machines, as they work under very severe conditions. As a rule, both centralised and individual lubrication are employed in automatic machines.

Gauged rods, wire and, more rarely, bar and ribbon are usually employed as stock for automatic forging and stamping machines. The stock used must have a smooth surface, be bright, free of cavities, cracks, burrs and other similar defects. To facilitate the defor-

mation of the stock and for the better preservation of the tools, the stock should be greased with a mixture of oil and crushed sulphur (sulphofrezol) before cold heading.

Every automatic forging and stamping machine is designed for stock of definite dimensions and shape and therefore should not be operated with stock for which it is not designed.

SCHEME OF ARRANGEMENT AND THE OPERATION OF AUTOMATIC FORGING AND STAMPING MACHINES

Automatic Cold Heading Machines. Automatic cold heading machines are employed for cold heading gauged wire or rod for the production of rivets, bolts, wood screws, etc. They are classified into "toggle joint" and crank-type cold heading automatic machines. The latter type is most frequently employed.

In addition, these automatic cold heading machines are classified into solid and open-die machines. The first are employed for cold heading work the shank length of which is less than 8 diameters of the wire or rod from which they are made. Automatic machines of the second type are employed for work with shank length greater than 8 diameters of the wire or rod from which they are made. In their turn, automatic solid and open-die machines are grouped into single-, double- and three-stroke automatic machines.

In a single-stroke automatic machine, the work is upset (headed) in one stroke of the punch; in the double-stroke—in two strokes and in the three-stroke—in three strokes of the punch. The single-stroke automatic upsetting machine can be employed only for heading bolts, etc., in which the length of the upset section does not exceed 2.0-2.5 diameters of the stock. These automatic machines are employed for manufacturing rivets, wood screws and similar components. Double-stroke upsetting automatic machines are designed for heading work, in which the length of the upset section does not exceed 4 diameters of the stock. Three-stroke automatic heading machines are designed for upsetting parts, in which the length of the upset section does not exceed 8 diameters of the stock. Double- and three-stroke automatic heading machines are designed for forming components of complicated shape with extra precision and clean surface finish.

Fig. 252 illustrates the *process of upsetting* (heading) a piece of work in an automatic heading machine. The wire or rod *1* is fed by continuously rotating grooved rollers *2* into the bore of cutting-off die *6* until it reaches stop *7*. As the wire or rod travels forward, a piece of stock of required length is cut off by cutter *8*, and pushed into the upsetting line by special mechanisms. The stock is pushed into the bore of die *4* by heading tool *5* until it meets rod *3*. The head

of the stock is upset by the further travel of heading tool *5*, after which heading tool *5* is retracted and the finished product ejected from the bore in die *4* by rod *3*.

Fig. 252, *a* illustrates the process of upsetting a head at one stroke, i. e., in a single-stroke cold heading automatic machine; Fig. 252, *b* illustrates the process of upsetting a head in two strokes in a

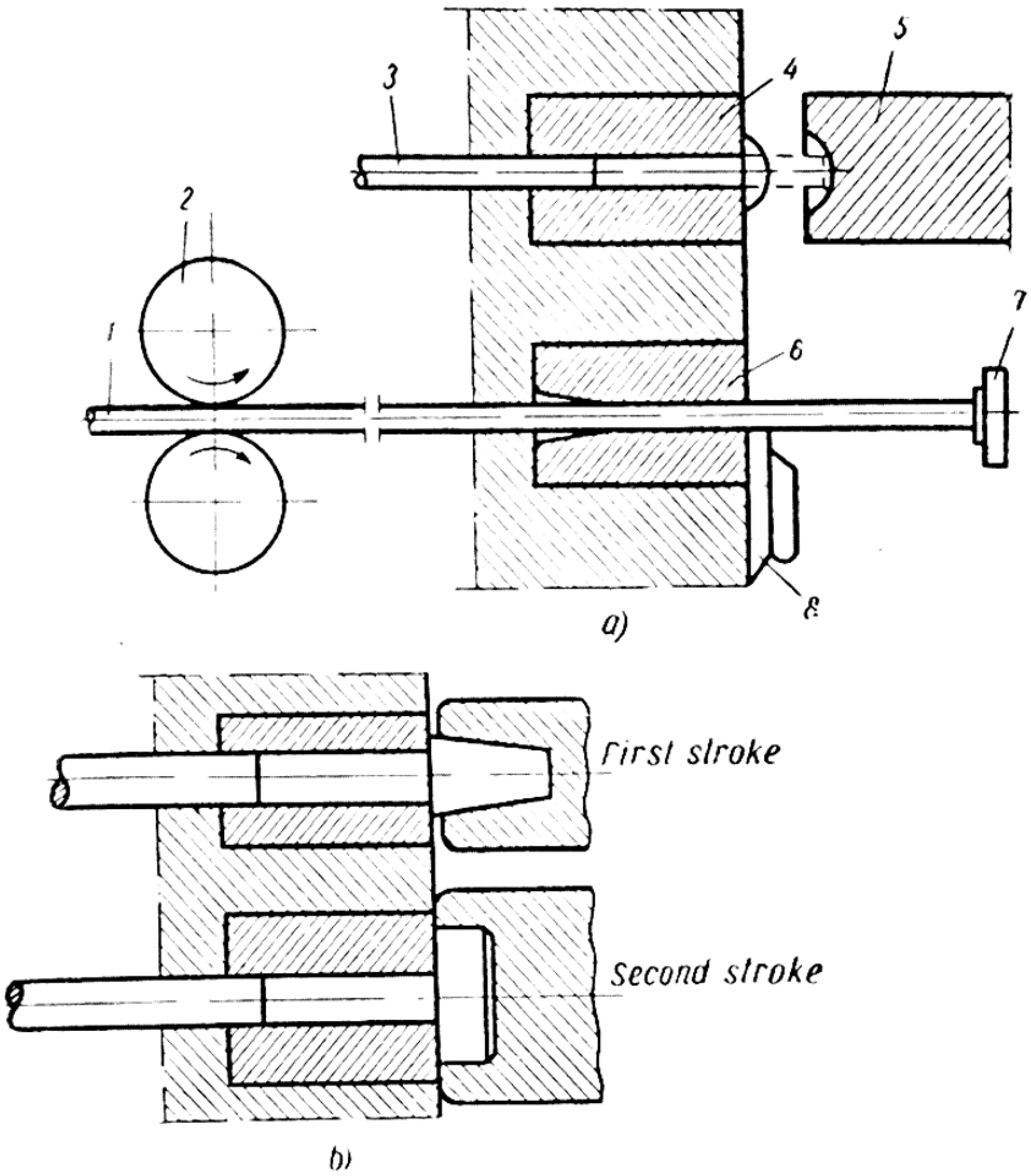


Fig. 252. Upsetting process in automatic heading machine

double-stroke cold heading automatic machine. After the first, forming, stroke of the punch the stock takes the form shown in the top section of Fig. 252, *b*; after this, the punch is automatically withdrawn and replaced by a second heading tool which performs the final upsetting operation, as shown in the bottom section of Fig. 252, *b*. Two (or three) strokes are brought about by securing the requisite number of heading tools in a specially designed slide, which travels in a carriage up and down its slide holder.

Cold heading automatic machines consist of the following main parts:

1) Mechanism for feeding the stock into the die, with a stock straightening fixture;

2) Mechanism for cutting the stock into blanks and transferring the cut-off blanks from the feed line to the heading line;

3) Upsetting heading tool slide holder;

4) Mechanism for shifting the heading tool slide holder;
5) Mechanism for ejecting the finished product.

Fig. 253 shows the AA120 6×50 mm double-stroke solid die automatic cold-heading machine; Fig. 254—the AA161 double-stroke

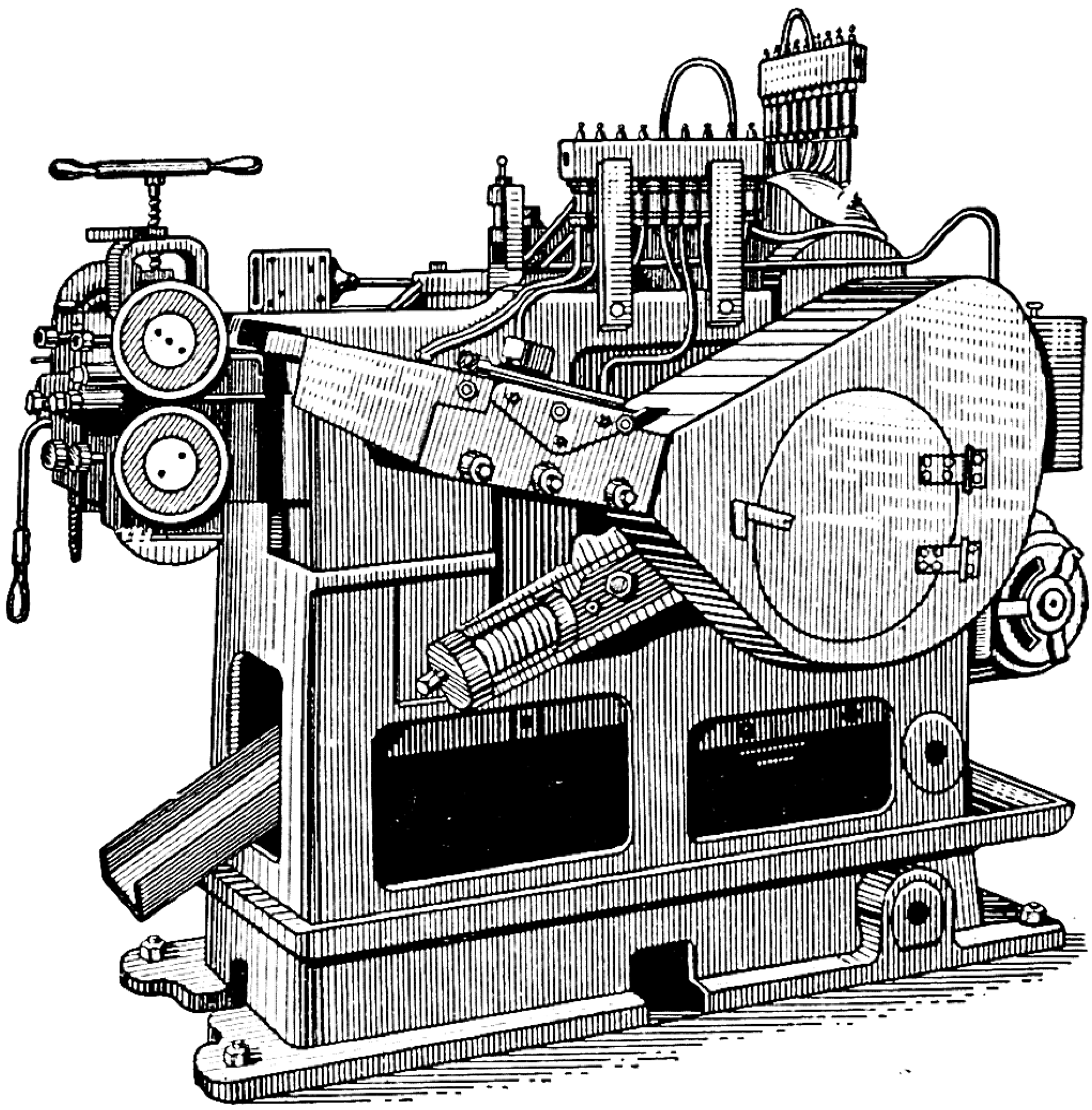


Fig. 253. The AA120 6×50mm double-stroke solid die automatic cold header

open-die automatic cold-heading machine. Modern automatic cold-heading machines are built to produce cold-headed products from rods up to 25 mm in diameter, the diameter of the cold-headed section being up to 50 mm. The productivity of such automatic machines ranges from 30 to 400 parts per minute, depending on the dimensions and shape of the product.

Bolts, screws, rivets and similar products from wire of gauges up to 6 mm in diameter are made on automatic open-die cold-heading machines; in these machines the blanks, after being fed against a stop, are cut off by the front edge of one of the dies and carried over from the feed line to the upsetting line, after which both dies are closed around the blank and the bolt head is preliminary formed by the heading tool. The slide is turned round, the second heading tool comes into operation and finishes the product.

The productivity of a double-stroke open-die automatic cold-heading machine ranges up to 270 parts per minute. They are operated by 7 kw, 970 rpm electric motors.

Automatic Cutting-off Machines. Automatic cutting-off machines are employed for trimming the flash from the preliminary upset section of the head of the product, usually of square or hexagonal shape. These automatic cutting-off machines can also be employed for reducing the diameter of the end of the shank of a bolt for threading, and also for gauging the cylindrical section (shank) of a bolt, simultaneously with the trimming of the flash from the head.

Fig. 255, *a* illustrates the *process of trimming a bolt* without reducing its shank, while Fig. 255, *b* illustrates the process of trimming the head of a bolt with the simultaneous reduction of the bolt shank for thread-rolling.

Automatic cutting-off machines operate as follows: stock bolt *1* is fed into the orifice of stationary die *2* by sliding die *4*. When die *4* and die *2* are in close contact, pusher *5* will exert pressure on the opposite end of the bolt, and the flash will be trimmed from its head. After the flash has been cut from the head of the bolt, die *4* will return to its original position, and the bolt will be ejected by ejector *5* through the hole in sliding die *4* (Fig. 255, *a*).

Fig. 255, *b* illustrates the *process of trimming the flash* from the bolt head with the simultaneous reduction of the end of the shank for

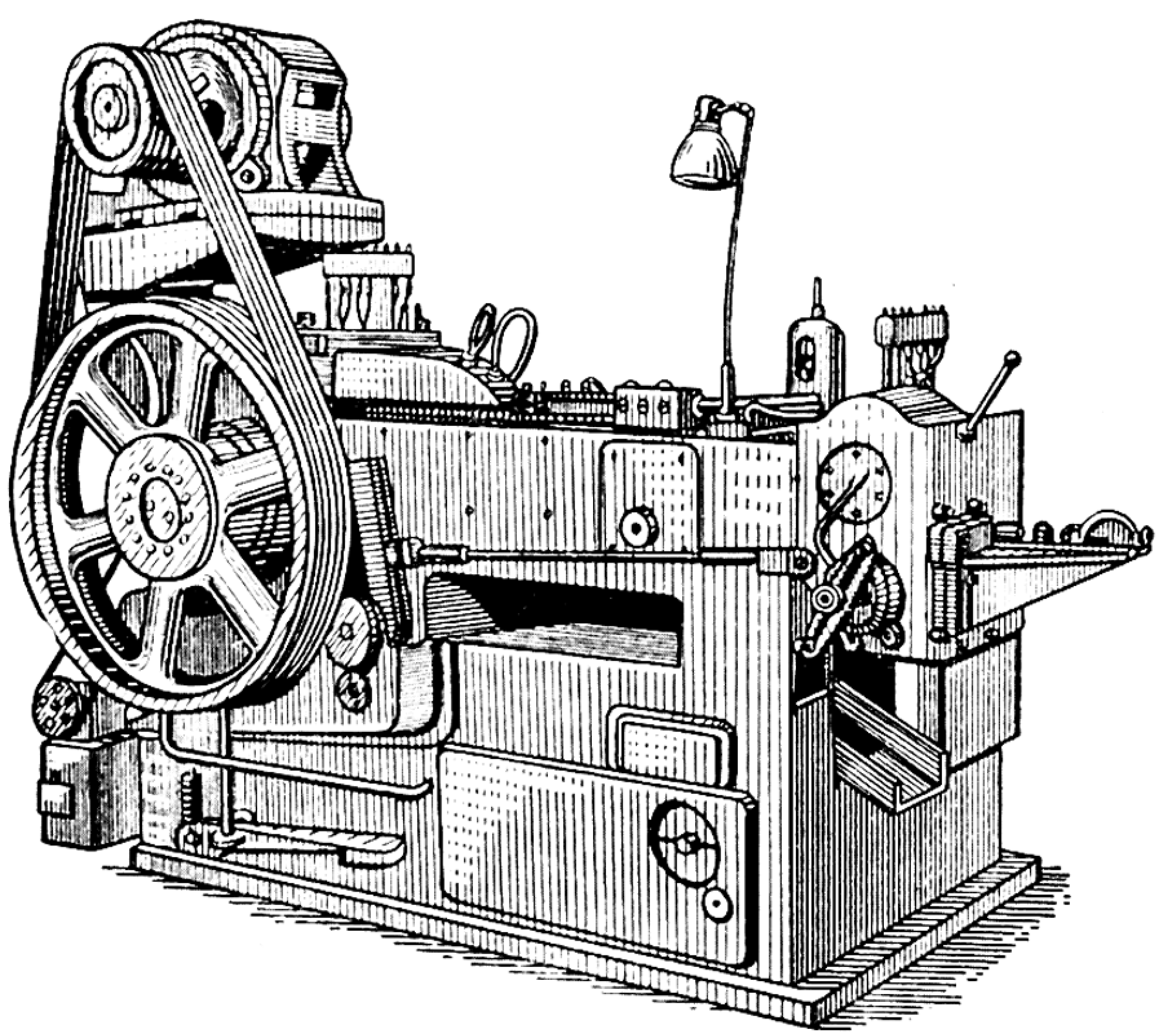


Fig. 254. The AA161 double-stroke open-die automatic cold header

subsequent thread-rolling. Here, drawing die *6* and intermediate ring *7*, which can be changed to suit the length of the shank to be threaded, are inserted into stationary die *2*. Before the bolt head is trimmed, sliding die *4* forces the shank of the bolt into the orifice of die *2*, thereby reducing the tail end of the shank to the required diameter for threading. The process of trimming the flash and ejecting the finished product takes place according to the lower illustration of Fig.255; *a*.

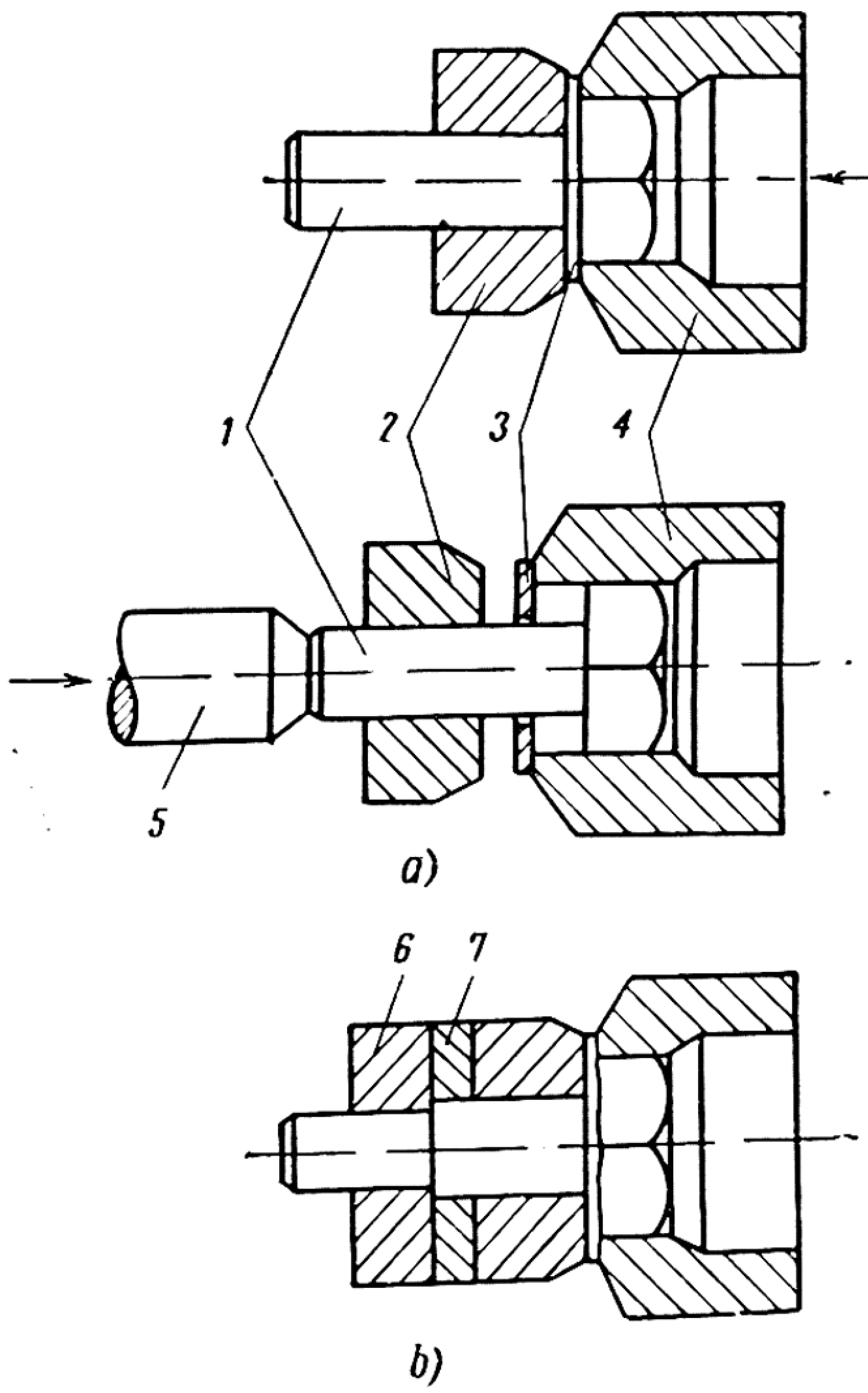


Fig. 255. Process of cutting-off bolt shank

In automatic cutting-off machines, the operations of feeding the stock, trimming the head, reducing the shank and ejecting the finished product are completely automised. The stock is loaded into a hopper, whence it is delivered to the feeder and transferred from the feeding line to the trimming line. These automatic machines are driven by individual electric motors through a gear drive. When reducing the shank of the bolt, the tools have to be cooled; in such cases, the coolant is delivered by a centralised forced feed system through a gear pump. The lubrication of these automatic machines is also centralised.

Automatic cutting-off machines are built to take stock of various dimensions: $6 \times \times 60$ mm; 10×75 mm; $10 \times \times 120$ mm, etc. Their productivity ranges from 75 to 130 bolts and more per minute.

Universal Automatic Forging Machine. Universal automatic forging machines, called bolt-linkers, have recently been brought into use. These machines are designed to execute all the operations entailed in making bolts—upsetting the head, trimming and threading the shank. Fig. 256 illustrates the *gearing diagram of such a machine*; the heading of the bolt is effected in the impressions *1*, *2* and *3* of the die; trimming the hexagonal head—in impression *4*, whence the bolt is automatically transferred to position *5* for thread-rolling. The pro-

ductivity of such a bolt-linker is 18,000 bolts in eight hours. One bolt-linker does the work of three bolt producing machines.

Automatic Railway Track Spike Producing Machines. The machines are designed for the mass production of railway track spikes from preheated rods.

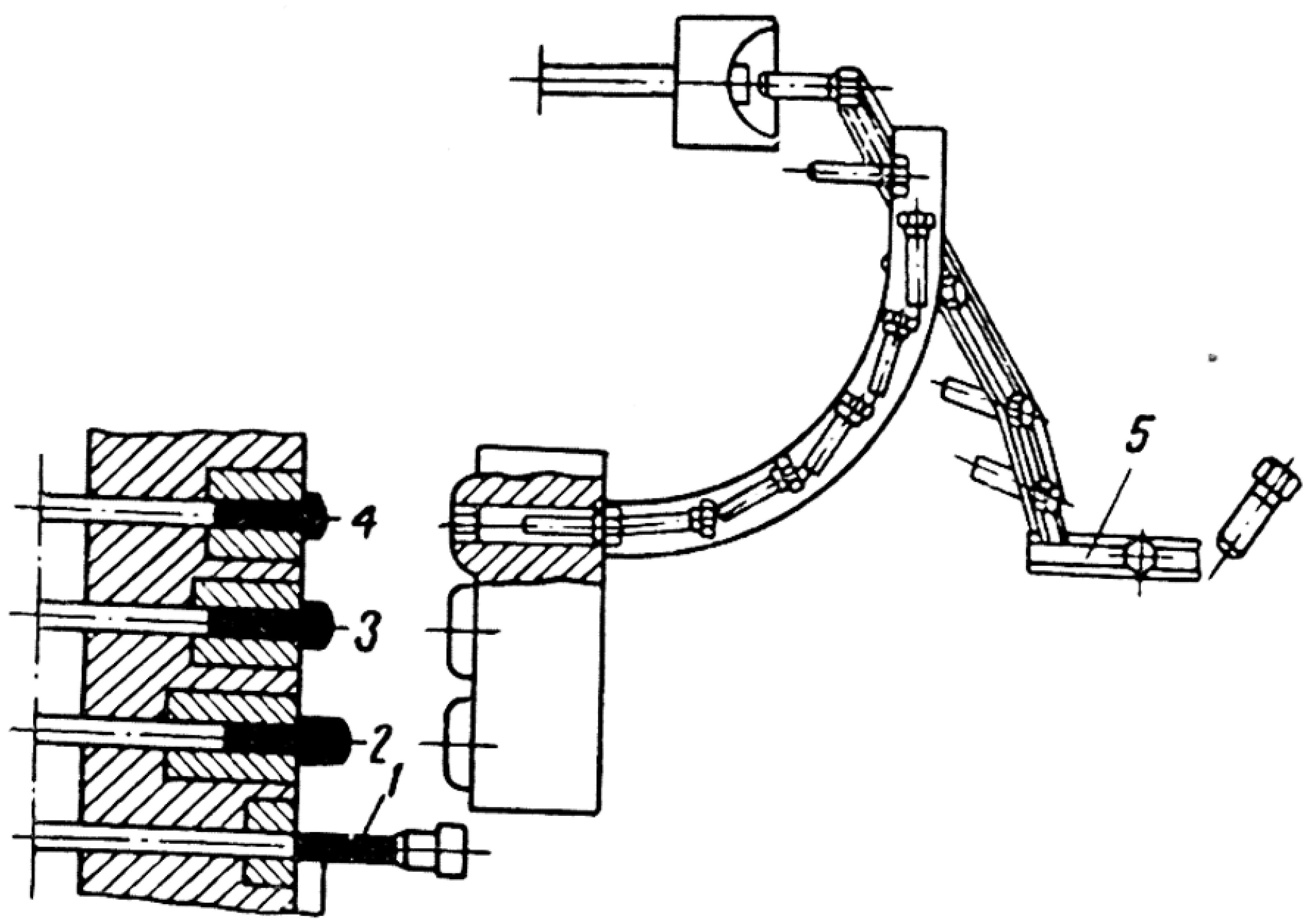


Fig. 256. Bolt-linker gearing diagram

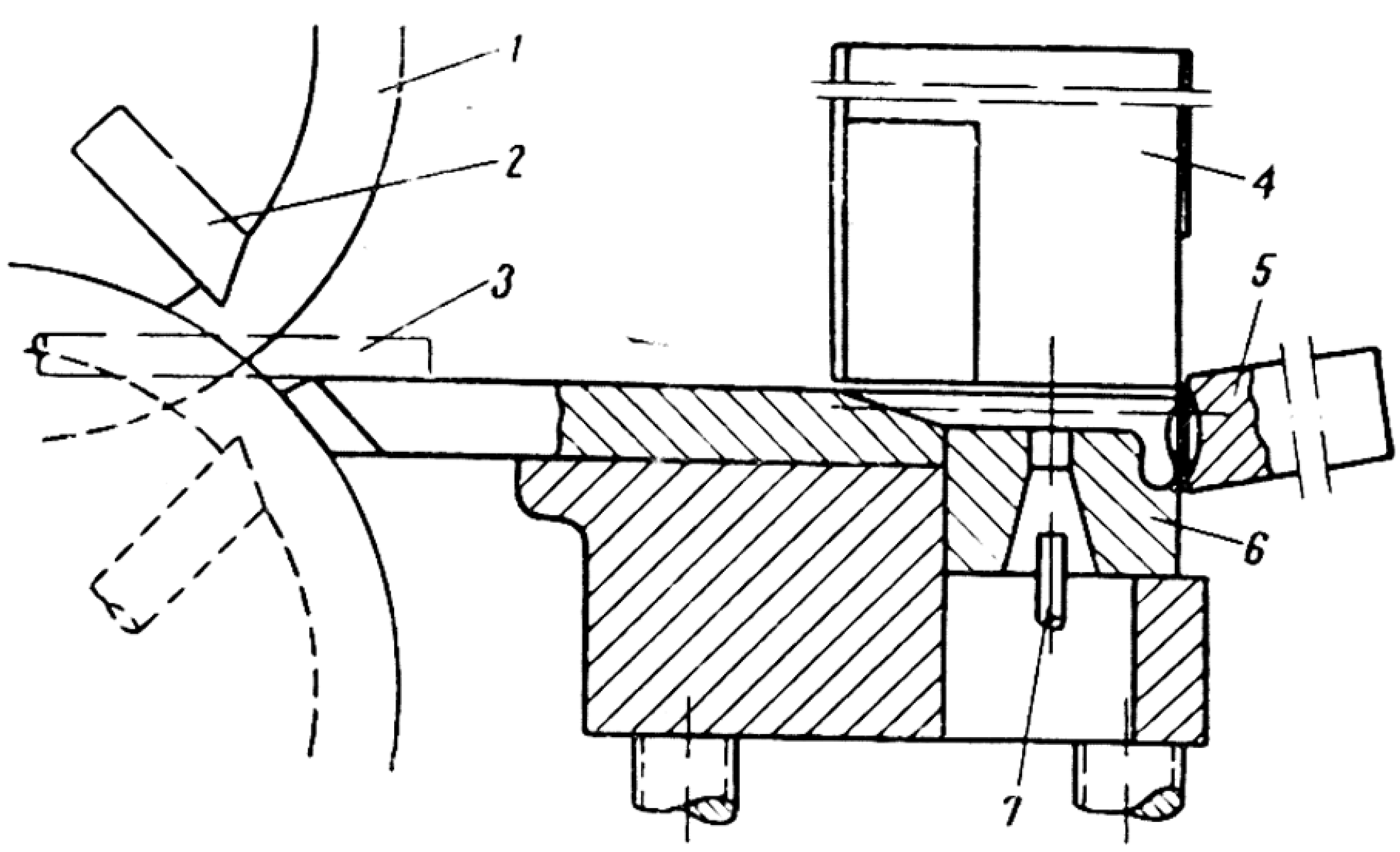


Fig. 257. Process of making railway track spikes on automatic cold header

In these machines, the operations of feeding the stock to the dies, pointing the end of the spike with subsequent cutting-off and transfer to the die, upsetting the head and ejecting the finished product are completely automatic.

Fig. 257 shows the *process of producing a railway spike* in one of these automatic machines. Square rod 3, heated to the required tem-

perature, is caught up and fed into the machine by rolls *1*. Simultaneously, its end is automatically trimmed to a point by trimming dies *2*, which are fixed in the feed rolls, and also partially cut off from the rod; after its end has been pointed, it is finally cut off with the aid of special tongs which also transfer it to die *6*. In die *6* the stock is held in position by sliding die *4* and its projecting end upset by punch *5*, after which sliding die *4* travels upwards and the punch—back-

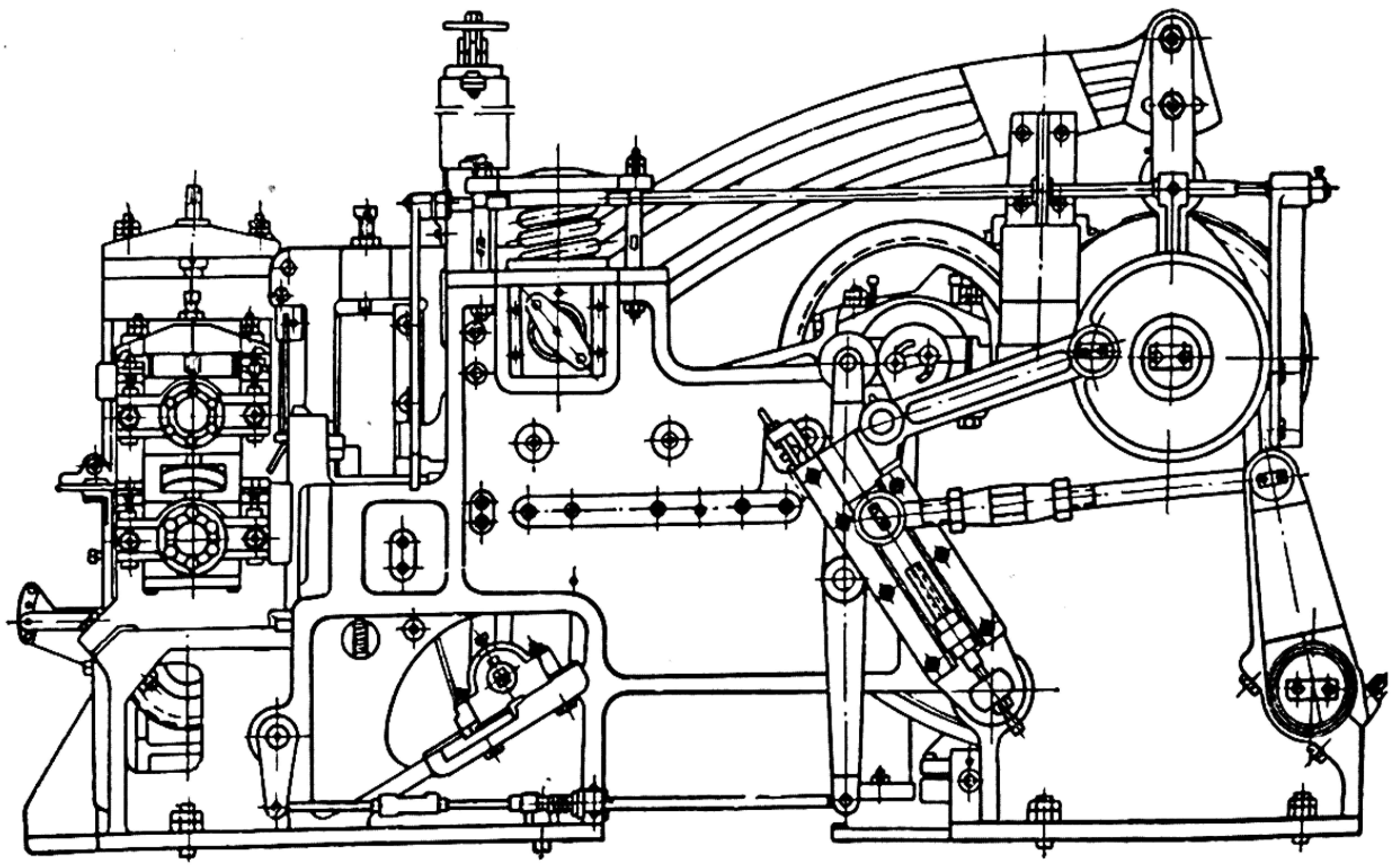


Fig. 258. Railway track spike automatic cold-heading machine

wards. The finished spike is ejected by ejector *7* which passes through the bore in die *6*.

Fig. 258 shows the side elevation of a 16 × 16 automatic railway track spike producing machine, with a capacity of 85 spikes per minute. The speed of its crankshaft is 85 revolutions per minute, i. e., one spike is produced per revolution of the crankshaft. It is push-button controlled; lubrication—centralised force feed and individual.

Automatic Bending Machines. Automatic bending machines are designed both as universal and highly specialised bending machines. The former are intended for manufacturing various types of work from wire or bar stock, such as: cotter pins, clips, hooks, staples, etc.; special automatic bending machines may only be used for the manufacture of the product for which they are designed, such as: spring washers, chain links, etc.

In most cases, these machines work on cold stock; hot stock is used only for work of large cross-section. Universal bending machines are most common in use, and are designed for the production of articles from wire ranging in diameter from 0.8 to 12 mm and from flat stock (ribbon) from 2 to 25 mm in thickness.

The chief mechanisms of universal bending machines are: the feed mechanism, cutting-off and 1st bending operation mechanism, side bending slides, final bending slide, and the ejector. Fig. 259 shows

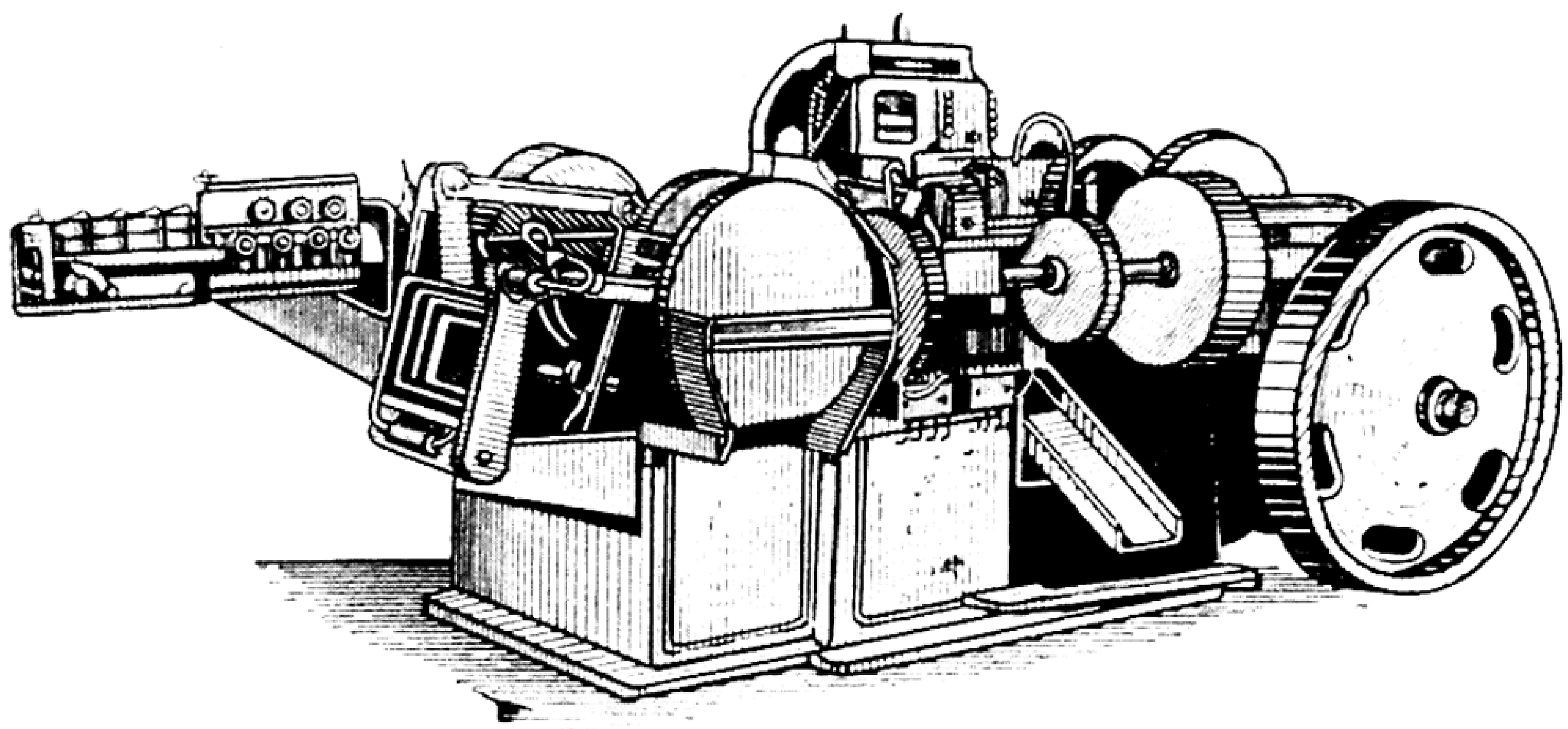


Fig. 259. The A914 automatic bending machine

the A914 *automatic bending machine*, designed for bending various articles from round wire and ribbon. When fitted with special tools and devices, this automatic bending machine can execute the following operations: point ends, punch holes of various sizes in ribbons, crimp (corrugate) ribbon, etc. Four bending slides and a vertical forming mechanism, equipped with an ejector, effect the bending operations on these automatic machines.

The feeding of the wire, straightening and cutting the stock, bending and ejecting the finished product are all automatic operations. The machine is driven by an individual electric motor through a V-belt drive; lubrication is individual. Its main specifications are as follows:

Maximum diameter of wire	5 mm
Maximum width of ribbon	40 mm
Maximum length of stock	480 mm
Maximum diameter of rings produced	40 mm
Productivity (capacity)	80 parts per minute
Electric motor rating	2.8 kw

CHAPTER XIII

DROP-FORGING (HOT STAMPING)

THE MAIN TYPES OF DROP-FORGING EQUIPMENT

As distinguished from hammer forging, in which the blacksmith directs the flow of metal with the aid of various tools, in drop-forging the flow of metal is limited by the surfaces of the impressions cut in the die block, in which the metal is forced to take its final shape and dimensions. The production of drop-forgings requires a set of dies for each piece of work.

Dies are steel blocks into which an impression or impressions are machined in the shape of the work to be stamped in them. Dies are made in pairs (top and bottom dies).

Drop-forging occupies a very important place as compared with other hot-working processes. It has been calculated that, in the Soviet Union, about 20 to 25 per cent of all metal is drop-forged. Thus, about 80 per cent by weight of the components of a modern automobile are drop-forgings; of aircraft—about 85 per cent; locomotives—up to 60 per cent, and so on. In mass and large-scale production, forged parts are produced mainly by the drop-forging process, as hammer forging is not profitable for such large scales of production.

When manufacturing forgings on a small scale, for instance, when a shop makes only 30 or 50 similar forgings per year, it is unprofitable to employ the drop-forging process, because the expense of making the dies would considerably increase the price of the forgings; such forgings are cheaper to make by hammer forging or by stamping in insert dies.

Combined forging and stamping (die-forging) on high production equipment (crank-type forging presses) is employed instead of hammer forging in small-scale or individual production, for making forgings up to 30 kg in weight. Special dies and fixtures are used, and forging is carried out according to a special technological process in which the former complicated technology is broken up into separate simple operations performed in a definite sequence in the impressions of the die or fixture.

The advantages of die-forging as compared with hammer forging are not merely limited to saving time. The dimensions of die-forgings are much more precise than those of hammer forgings; die-forgings

are made with much smaller machining allowances, considerably reducing the machining time and the consumption of metal required for the production of the forgings. Die-forging too permits the manufacture of forgings of very complicated shape; and the operation of die-forging hammers and presses does not require such highly skilled workers as that of smith hammers.

Forgings produced in die-forging hammers are always exact duplicates of each other; their subsequent machining is thus greatly facilitated; they can be machined in special jigs and fixtures, on automatic machine tools, etc. In many cases, their mechanical properties are much higher than those of hammer forgings; this is due to the fact that, when die-forging, it is very easy to create the necessary conditions in the dies for distributing the metal fibre so as to ensure the high mechanical qualities required from forgings designed for heavy duty. As has already been stated, die-forgings require less metal than hammer forgings.

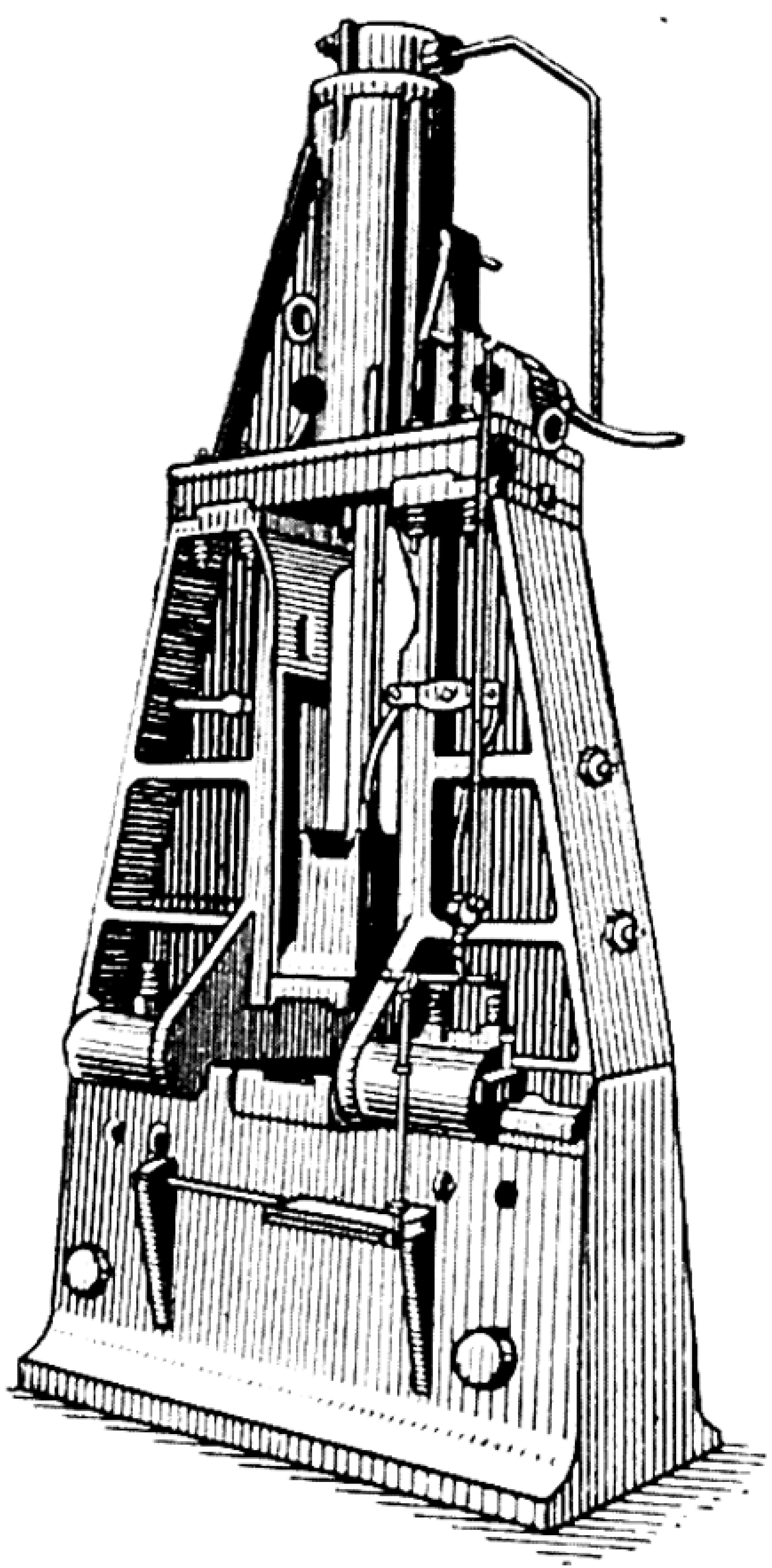


Fig. 260. Steam-and-air drop-forging hammer

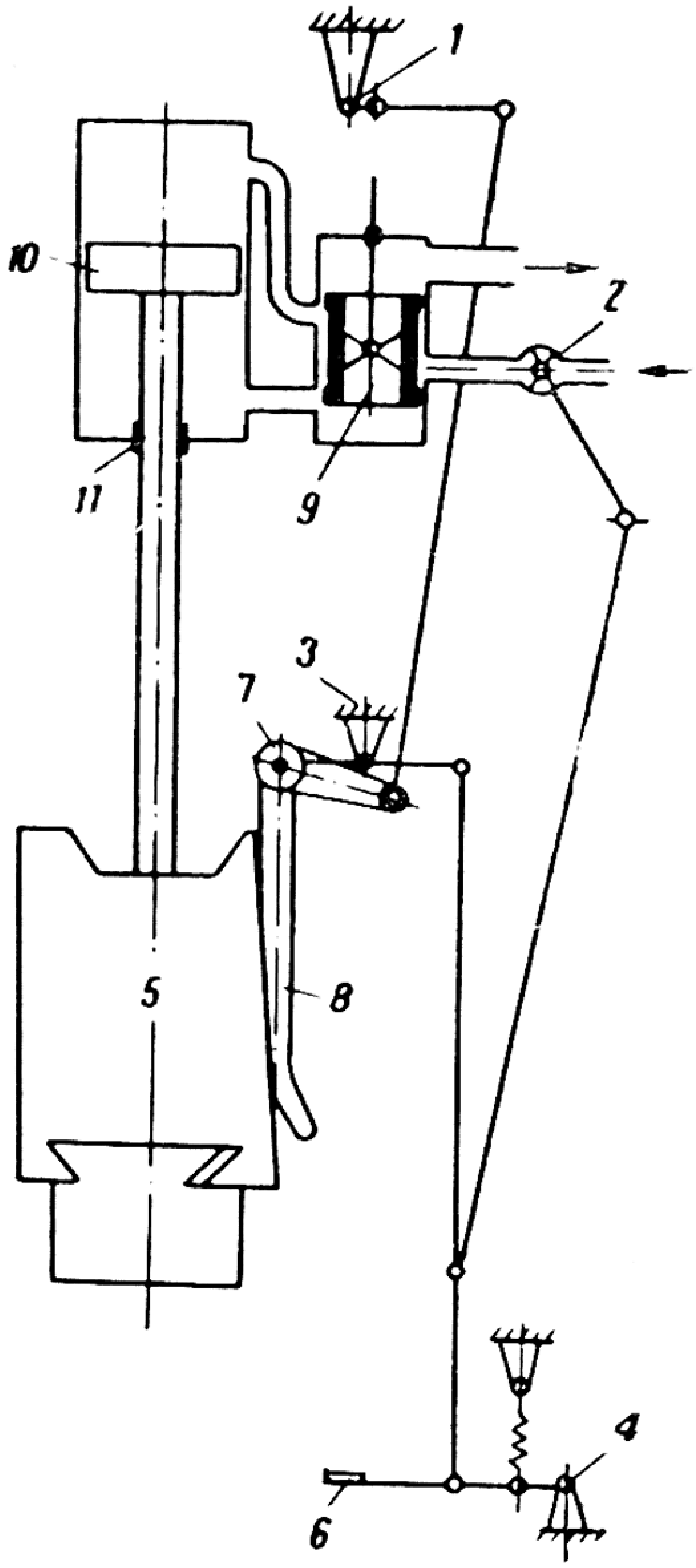


Fig. 261. Control diagram of steam-and-air drop-forging hammer shown in Fig. 260

The following types of equipment are employed for die-forging: drop-forging hammers, power-driven presses, hydraulic presses and horizontal forging machines.

Drop-Forging Hammers. Drop-forging hammers are very similar in design and arrangement to the steam hammers already described. They differ from the latter chiefly in that the frames of steam forging hammers are secured to their anvil blocks, whereas the frames of drop-forging hammers are secured to special foundations independent of their anvil blocks.

The frame of a drop-forging hammer is secured to its anvil block in order to achieve rigidity of construction and precise alignment of the top and bottom dies during their impact, thereby ensuring the precision of the required shape and dimensions of the forging.

Another great advantage of drop-forging hammers is that their blows can be regulated over a much wider range than in steam hammers—from the lightest to the heaviest, as required. Their control and operation are much simpler. Drop-forging hammers do not require a hammer operator—the die forger himself operates the hammer by manipulating the treadle with his foot. Fig. 260 shows a *steam-and-air drop-forging hammer*.

Drop-forging hammers are built in capacities ranging from 0.5 to 100 tons. Such hammers require very heavy anvil blocks, and also cumbersome foundations. For this reason drop-forging hammers without anvil blocks have recently come into use. As distinguished from ordinary drop-forging hammers, they are built without anvil blocks and cumbersome foundations. They have two rams which travel towards each other, i. e., the top die falls to meet the bottom die which travels up.

Drop-forging hammers are controlled by the hammer operator through a system of levers. The *control diagram* of a drop-forging hammer is shown in Fig. 261, from which it can be seen that the system of levers hinges at four points: at rotary valve *1*, at throttle *2*, on hammer frame *3* and at foot treadle *4*. Ram *5*, on being moved from its central position by a light pressure on foot treadle *6* commences automatically to swing up and down. So long as the foot treadle is not touched, point *7* will remain stationary. Lever *8* is pressed against the tapered side of the ram and swings to the left and right transferring its motion to valve *9*. When the ram makes its down-stroke, the valve falls and steam (or air) begins to flow into the working cylinder under piston *10*, forcing the ram, through the piston rod, to reverse its stroke. During the up-stroke of the ram, the valve will rise and steam (or air) will flow into the working cylinder above piston *10*, again reversing the stroke of the ram. This cycle can be repeated as long as necessary.

In order to deliver the blow, the operator must depress treadle *6*

at the moment when the ram begins to make its down-stroke. Then point *7* will move upwards and, as lever *8* is still pressed against the ram, it will cause the valve to rise very rapidly. Simultaneously, throttle *2* will open to its full extent, and a blow will follow. If the treadle is depressed after this, lever *8* will cause the ram to rise rapidly and to return to its automatic swinging position.

Thus, the main task of the entire system consists in the automatic raising of the ram. Blows are brought about by the hammer operator depressing the treadle; and their force, which can be regulated at the operator's desire, depends on the pressure of his foot on the treadle and, consequently, on the degree to which the air channels of the valve are opened; for the greater the volume of steam or air delivered into the working cylinder per unit of time, the greater will be the force of the blow, and vice versa.

Forging Presses. Drop-forging is effected: a) in hydraulic and steam-hydraulic presses of the vertical and horizontal type, and b) in power-driven presses. Hydraulic and steam-hydraulic forging presses are employed in the same way as drop-forging presses, and are usually employed for the manufacture of heavy forgings.

Hydraulic and *steam-hydraulic presses* are particularly advantageous for the stamping of hollow forgings from plate stock (10-25 mm and over) instead of from ingots or rolled shapes, as used for hammer forgings.

Power die-forging presses are classified into *friction* and *crank types*. Their design depends on the character of the work to be performed. Their capacity is indicated in tons. The capacity of a press is the pressure which it can develop. If, for instance, the capacity of a friction press is indicated as 100 tons this means that the press can develop a pressure on the metal equal to a hundred tons.

Presses should never be employed for forging or stamping work requiring for its deformation a greater pressure than that for which the press is designed; otherwise the press may break.

For this reason, work should always be executed on a press of the capacity indicated in the technological chart. Below several presses of different design are described.

Screw-friction presses. These presses are employed for bending and stamping operations.

The arrangement of the friction press shown in Fig. 262 is as follows: nut *2* with a square thread is fastened inside frame *1*; through this nut passes screw *3*, the tail end of which is connected to slide *4*, and its head—to flywheel *5*. Horizontal drive-shaft *6* with two discs *7* is located above the flywheel. The distance between the discs is somewhat greater than the diameter of the flywheel. Because of this, when one of the discs is in contact with the flywheel, there will be a slight clearance between the second disc and the flywheel.

By moving one or other of the discs to touch the flywheel, the screw can be made to rotate clockwise or anticlockwise, thus raising or lowering the slide, and increasing or decreasing the working clearance *9*. Drive-shaft *6* together with its discs can be moved to the left or to

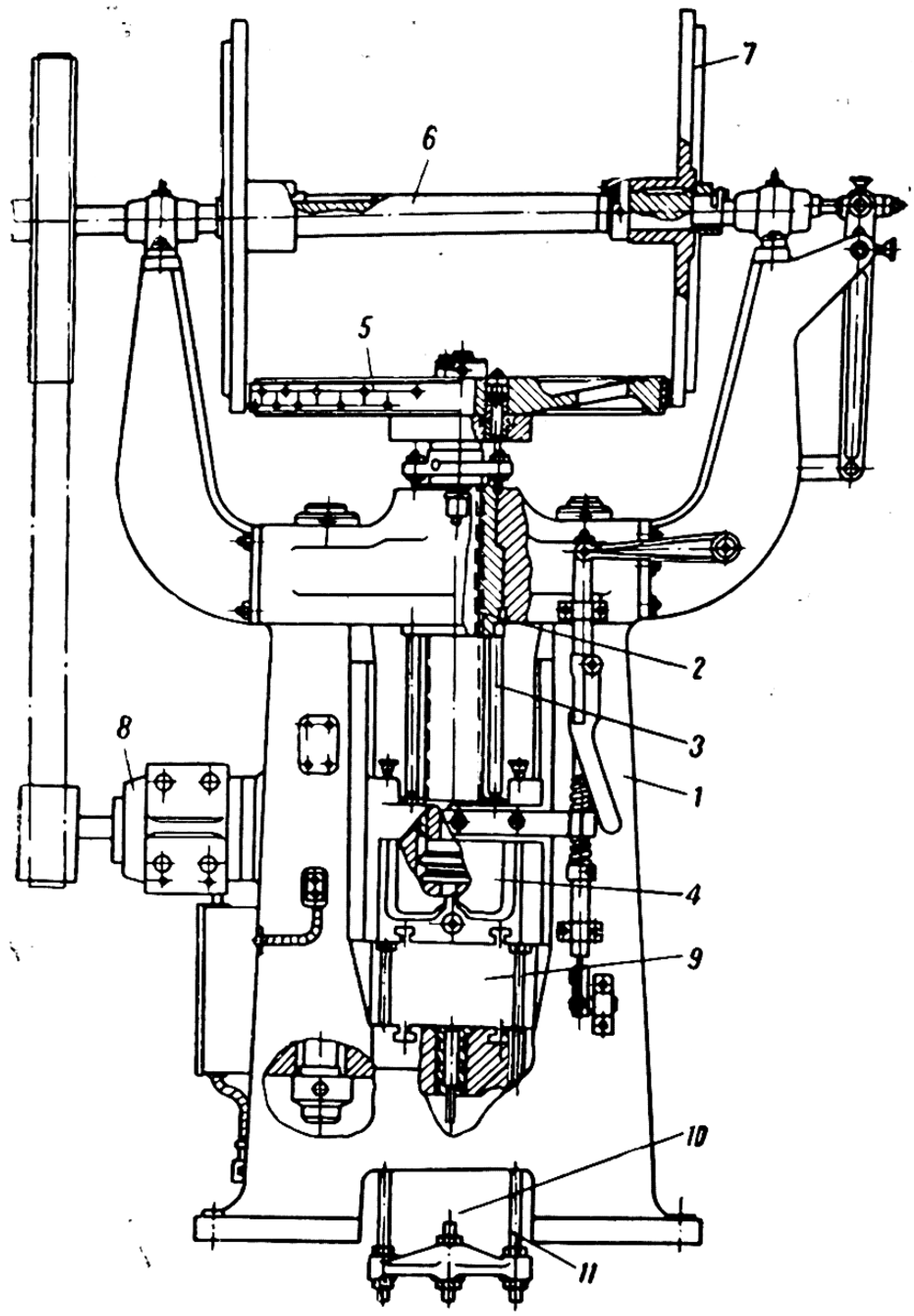


Fig. 262. Double-disc friction drop-forging press

the right through a system of levers actuated by a handle or by a foot treadle. The speed of the screw increases as it falls. Because of this, the increase in the pressure of the slide of a friction press is not so smooth as in an eccentric or crank-type press—it is accompanied by a blow. For this reason, friction presses are sometimes called screw-friction hammers.

This feature permits friction presses to be successfully employed for bending and straightening operations and also for upsetting bolt-heads. For such operations, ejector *10*, through screws *11* connected to the slide, will push, or eject, the forged work from the dies (see Fig. 262). Friction presses are less suitable for sheet-drawing operations,

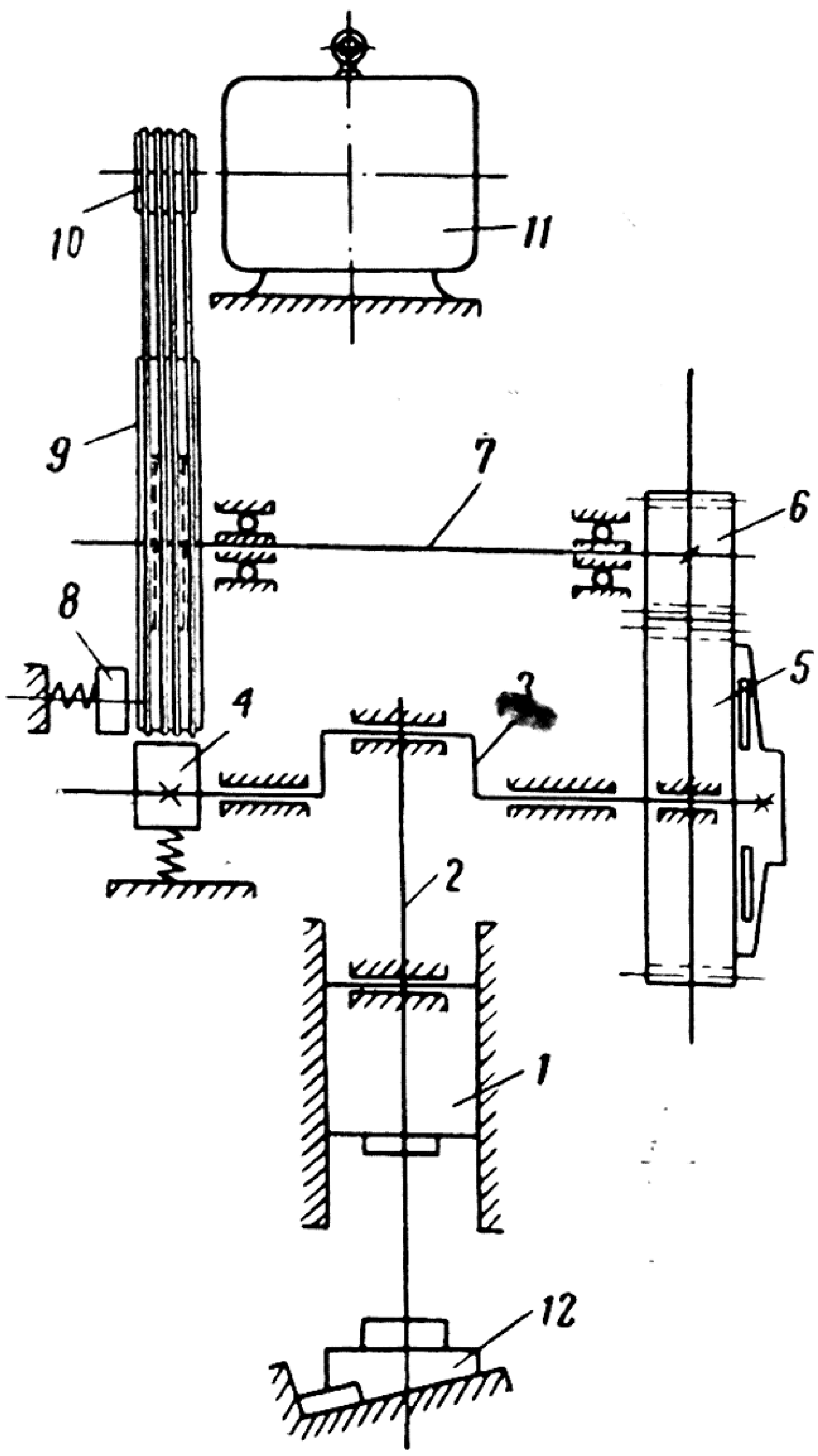


Fig. 263. Gearing diagram of crank-type drop-forging press

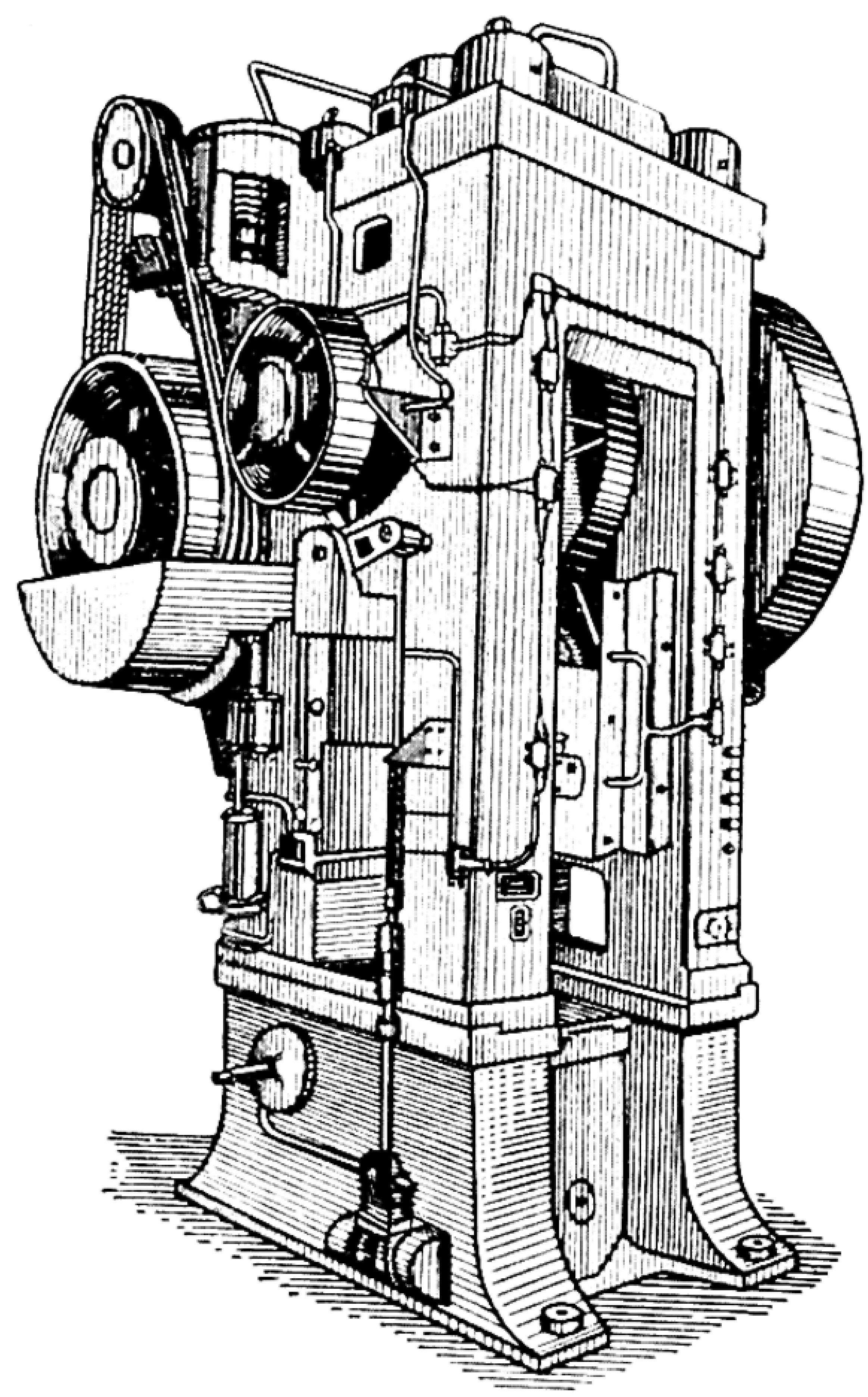


Fig. 264. The K862 crank-type drop-forgi

which need a smooth application of pressure, or for trimming operations, as the dies are liable to more rapid wear and destruction as a result of the sudden impacts to which they are subjected in these presses.

Crank-type presses. At present, however, powerful universal crank-type presses designed by Soviet engineers in conjunction with skilled blacksmiths are being increasingly widely used, and successfully employed for die-forging many types of complicated forgings.

Crank-type die-forging presses possess considerable advantages compared with conventional drop-forging hammers for the production of light forgings, and they can be successfully used instead of 3-4-ton capacity drop-forging hammers. Their employment sharply increases the labour productivity, reduces the cost of production and greatly improves working conditions.

Fig. 263 shows the gearing diagram of a *crank-type die-forging press*, and Fig. 264—a crank-type drop-forging press.

From Fig. 263 it can be seen that the press is driven by electric motor *11*, which rotates flywheel *9* through pulley *10* and a Vee-belt drive. Flywheel *9* is mounted on shaft *7*, and is equipped with a friction protection device which limits the torque on the shaft. Auxiliary brake *8* serves to stop flywheel *9*, shaft *7* and the large gear. Brake *8* is brought into action automatically after electric motor *11* is switched on. Main shaft *3* is rotated by gears *6* and *5*. Brake *4*, designed for stopping main shaft *3*, connecting rod *2* and slide *1*, is mounted on the left-hand end of shaft *3*. Slide *1* travels between guides of the frame and is actuated by main shaft *3* through connecting rod *2*. Brake *4* closes after the electric motor has been switched off. Double-tapered device *12* is designed for adjusting the working clearance of the press.

At the present time, the Soviet Union is producing crank-type drop-forging presses of up to 4,000-tons capacity, and presses of greater capacity—from 6,000 to 10,000 tons and upwards are in the process of construction. To find the capacity of a forging press corresponding to that of a forge hammer, the following formula is used: one-ton capacity of a drop-forging hammer is equivalent to a pressure of 1,000 tons developed by a forging press. Thus, a 4,000-ton crank-type forging press can be substituted for a 4-ton capacity drop-forging hammer.

TOOLS AND FIXTURES FOR DROP-FORGING

The tools and fixtures employed for drop-forging are classified as main and auxiliary tools. *Main tools include*: dies which are in turn sub-classified into forging and trimming dies. Forging dies are employed for the production of the forging itself, while trimming dies are employed for cutting-off, or trimming the flash after forging.

Drop-forging auxiliary tools and *fixtures* include:

1) Handling fixtures and implements; they are used to charge the metal into the furnace, deliver the metal to the hammer from the furnace, deliver the stock or forging from one hammer or press to another, etc.;

2) Tools and fixtures which place the stock on the hammer or in the press for forging, move the forging from one impression to another and also remove it from the dies when finished;

3) Measuring instruments and templates for the periodical inspection (measurement) of finished forgings.

Dies. As has already been mentioned, dies are blocks of steel having machined impressions in the shape of the forgings to be made in them.

Below the design of several dies is examined. For instance, suppose that a *gear blank with a boss* as shown in Fig. 265 has to be stamped, i. e., drop forged. For this purpose a set of two dies is required. The gear blank, as shown in Fig. 265, *a*, cannot be produced by ordinary

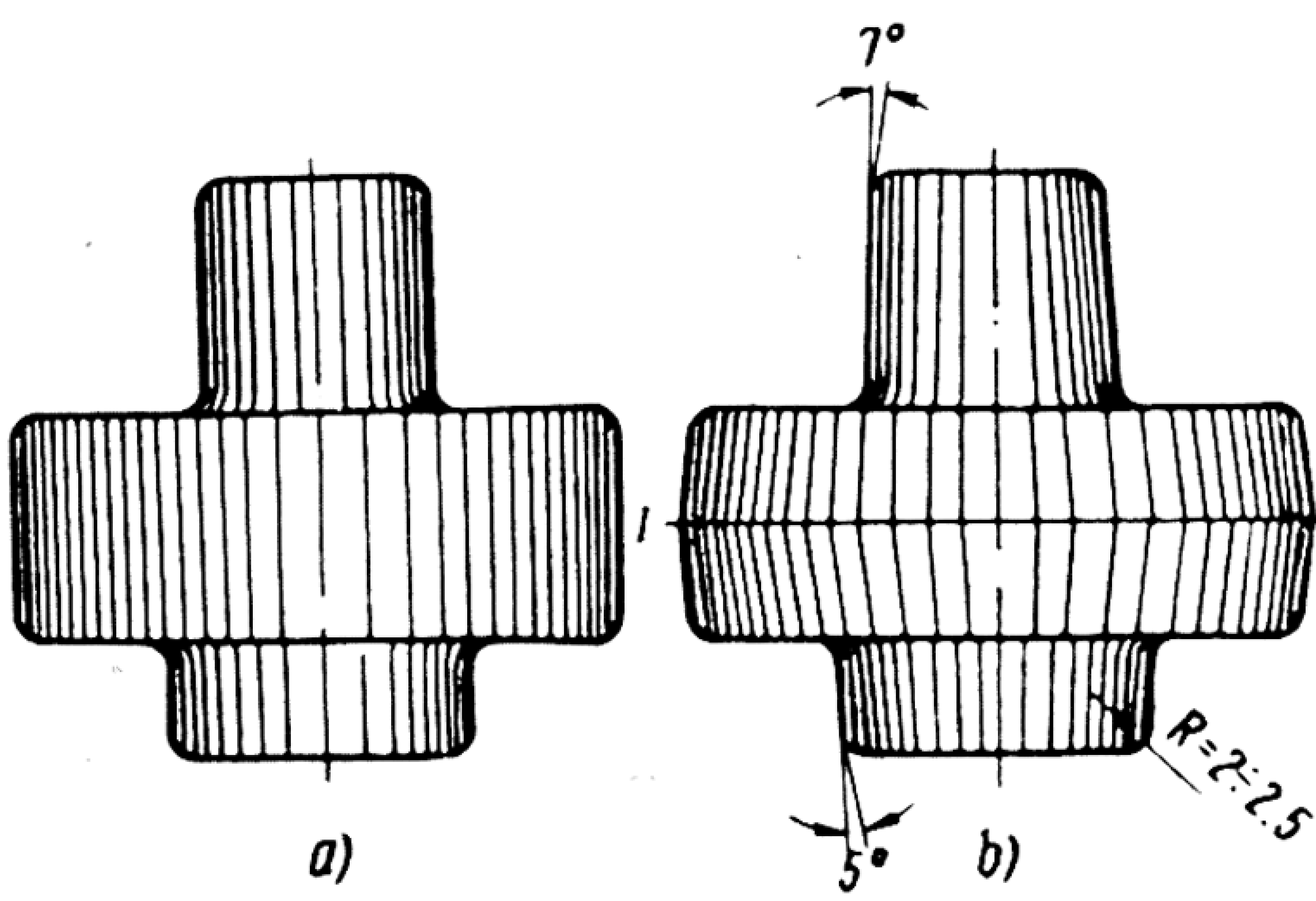


Fig. 265. Gear blanks:
a) hammer forged; b) drop-forged

hot stamping. Its shape after stamping will be as shown in Fig. 265, *b*. This difference in shape between the forging and its drawing is explained by the fact that the side walls of the impressions of a die are never made vertical, as otherwise the forging would stick in the impressions of the die and its withdrawal would be very difficult. Another reason for not making the side walls vertical is that the metal will not completely fill impressions made with comparatively high vertical side walls.

For this reason, dies with impressions having vertical side walls are made with what is called a forging draft, or taper, of up to 7° for outside surfaces and 10° for inside surfaces. The shape of the forging is changed because all the sharp corners in the die impressions (and, consequently, of the forging itself) are rounded, the radius of rounding ranging from 2 to 25 mm, depending on the depth of the impression in the die and on the size of the forging.

After correcting the forging drawing to correspond to the dies, it must be decided which section of the work is to be forged in the top die, and which in the bottom die. In other words it must be decided where to lccate the parting line of the die, i. e., the plane in which it must be parted. The selection of the parting line depends mainly

on the configuration of the forging and on the ability of the metal to completely fill the impressions of the die. When stamping in hammers, the metal flows less readily in the bottom die than in the top die, while when press-forging the impressions of both dies are uniformly filled by the metal. For this reason, the impressions for the more elevated parts of the work (ribs, etc.) must be located in the top die when drop-forging in hammers. Besides this the parting line must be chosen so as to ensure simplicity and low cost in the manufacture of the dies. In this case, a parting line through I-I is selected (Fig. 265, *b*). It is assumed that the gear blank will be produced by drop-forging in hammers; in this case, the upper higher section will be located in the top die, and the lower section in the bottom die.

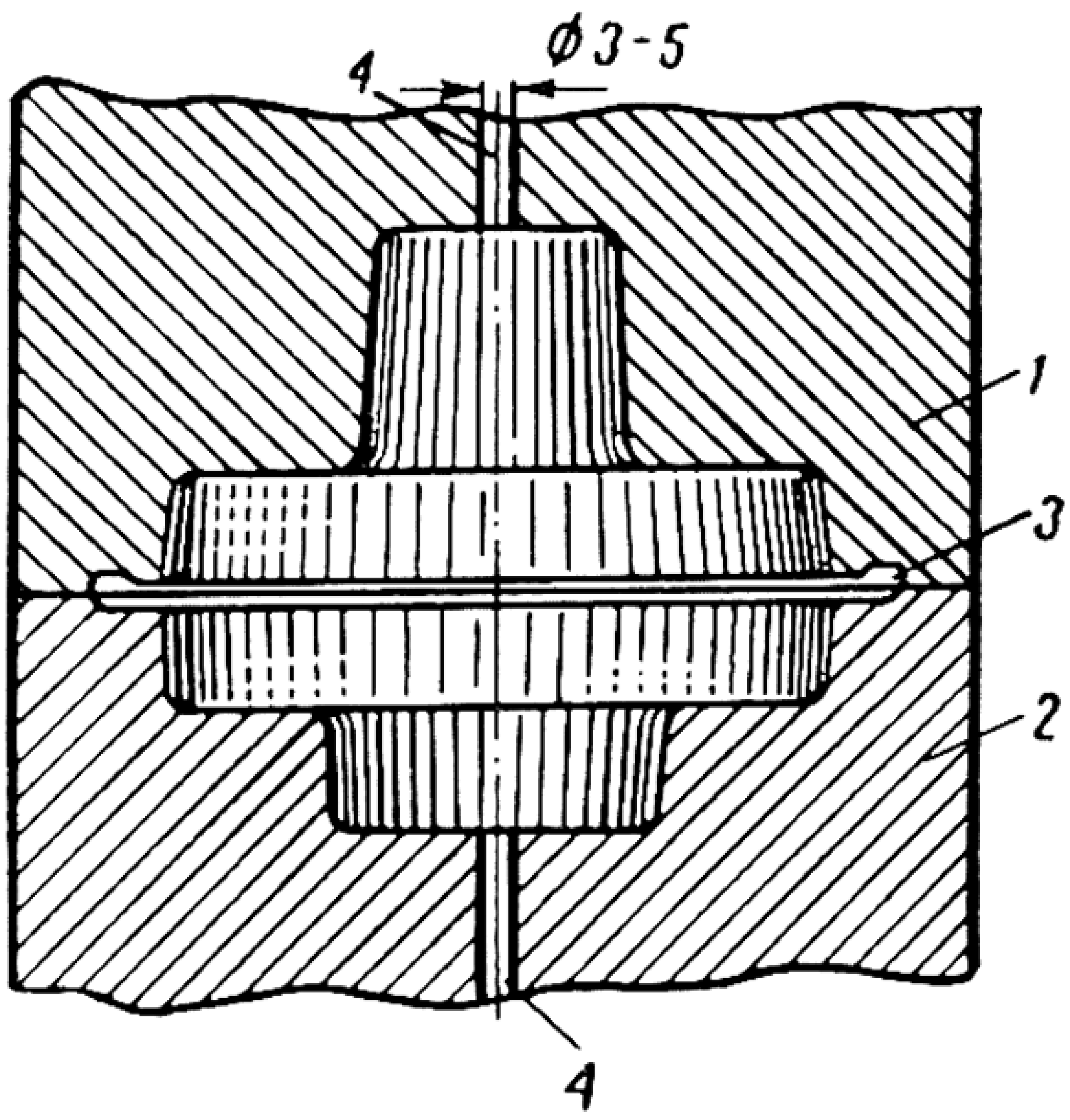


Fig. 266. Dies for drop-forging gear blank:
1) top die; 2) bottom die; 3) flash gutter

The gear blank forging dies will appear as shown in Fig. 266. This illustration clearly shows the special channel *3* or gutter, machined round the parting line, into which the excess metal, called flash, is forced from the body of the forging. This channel is called the flash pan (or flash gutter). In dies designed in this way, forgings will always be produced with flash, regardless of the shape of the forging and the blacksmith's wish. Even if a piece of stock is used whose weight is exactly that of the finished forging, the forging will still be produced with flash, and the dies will not be completely filled with metal; such forgings must inevitably be rejected. In such cases, i. e., when the stock is of the same weight as the forging, flash is developed because the metal flows, first of all, in the direction of least resistance. Until the top and bottom dies have not completely closed, it will be easier for the metal to flow, or spread out, sideways instead of filling the impressions in the dies. For this reason, when calculating the dimensions of stock for drop-forgings, a certain volume for flash must always be added to the volume of the finished forging. Depending on the shape, dimensions and weight of the work, the weight or volume of metal required for the flash will vary from 10 to 50 per cent, or even more, of the forging; moreover, the lighter the forging, the greater the relative weight of the flash will be. As it leaves the die impression, the flash will flow all around the forging and, if no special channel (flash gutter) is provided in the dies, the top and bottom dies will be unable to come into close

contact, with the result that the height of the forging will never be the same as that of the side walls of the die impression. To prevent this, flash pans, or channels, are machined around the impression, enabling the top and bottom dies to close completely at the end of the stamping (forging) operation.

Towards the completion of the operation, before the top and bottom dies have come into contact with each other, i. e., while the top die is still striking the hot stock, the sound of the blows will be rather dull.

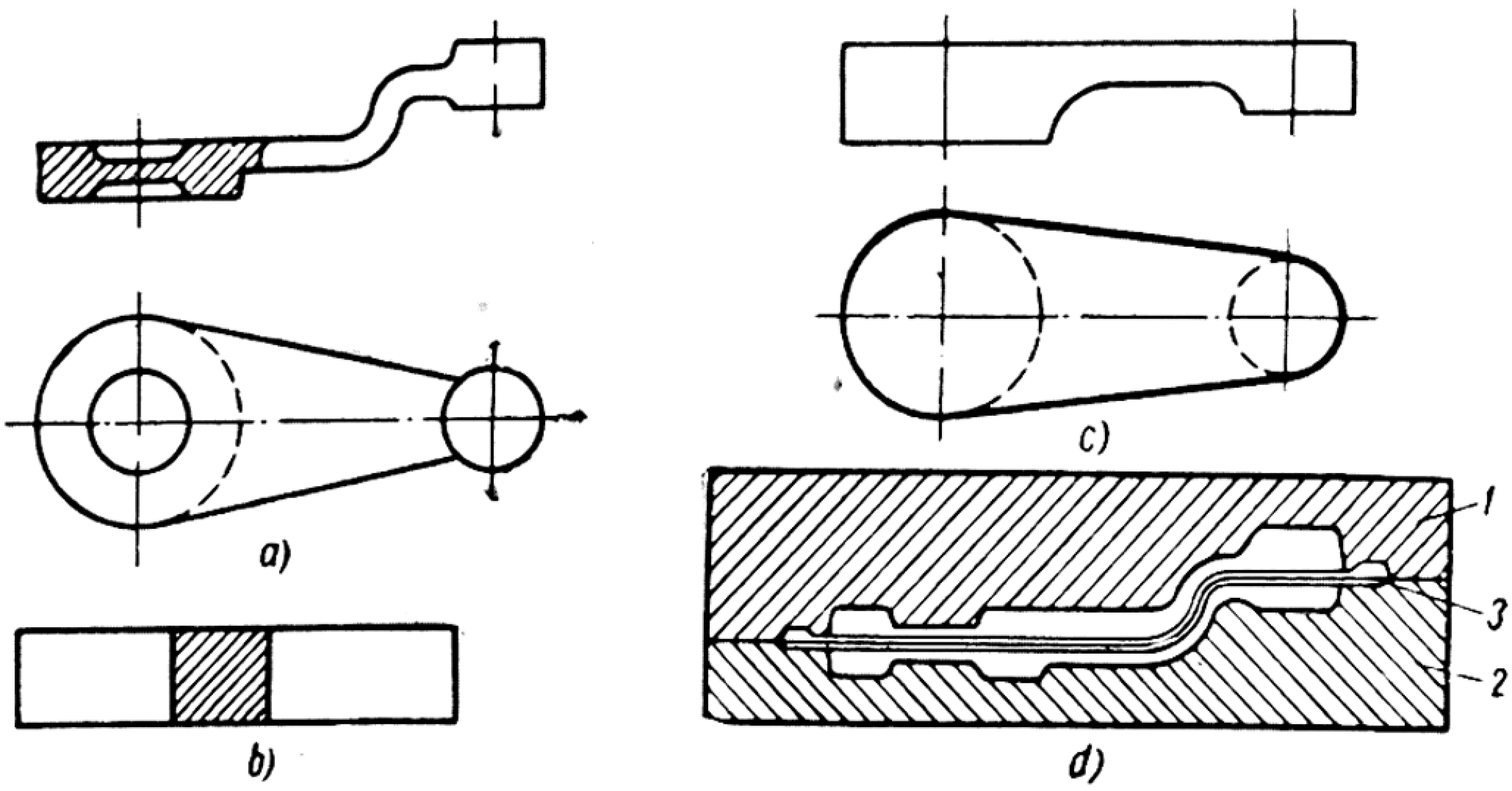


Fig. 267. Drop-forging a lever:
1) top die; 2) bottom die; 3) flash gutter; 4) air vent

But, as soon as the forging is completed and the top and bottom dies meet, they will strike each other with a sharp metallic rap; it is by this sound that the blacksmith knows that the forging is completed.

The *flash*, leaving the impression as a thin plate, cools more rapidly than the main mass of the hot stock. On cooling it increases in strength and becomes less plastic, the flow of metal from the impression into the flash pan perceptibly slows down and finally ceases, thereby facilitating the better filling of the impression.

When drop-forging in dies with deep impressions, the stock does not always completely enter the impressions of the die after being reheated; this results in the formation of a cushion of air between the bottom of the impression and the stock; on being heated (by the hot metal) this air expands and acts as a shock absorber when the stock is struck, ejecting the forging from the impression. To prevent this happening a vent *4* is incorporated to allow the air to escape from the dies (see Fig. 266).

As regards the drop-forging of the gear blank under discussion, no preliminary forging of the stock is required. The length of round or square stock cut off from the bar is heated in the furnace, placed on

end in the centre of the bottom die and forged into a gear blank with a few strokes of the top die.

Parts of more complicated shape, as, for instance, the *lever* shown in Fig. 267, *a*, are forged in a different manner. The shape of the stock for this forging is as shown in Fig. 267, *b*. If such a piece of stock is placed straightaway in the impression of the bottom die, the required forging will not be obtained: the metal will flow in the direction of the least resistance, fill up the central section of the die impression, producing very thick flash, and the corners of the impression will not be filled. For this reason, the stock is first rough formed, as shown in Fig. 267, *c*, and then stamped to the required shape between the dies, as shown in Fig. 267, *d*.

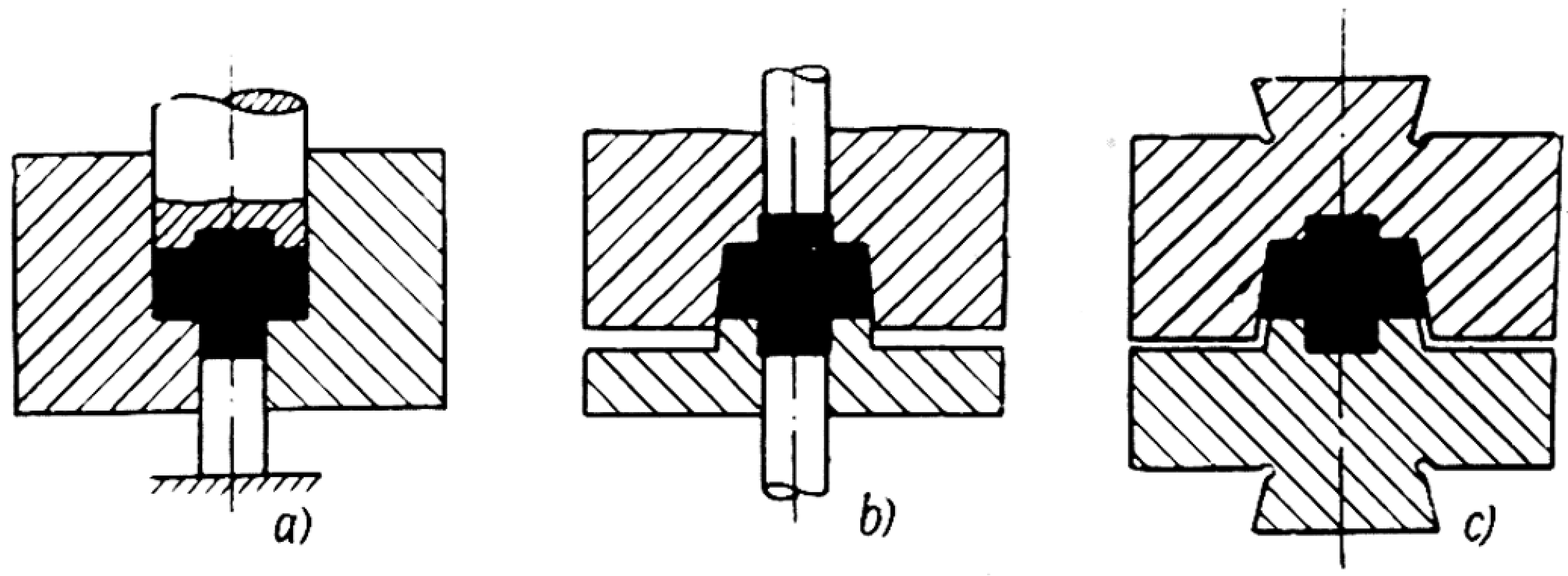


Fig. 268. Scheme of drop-forging in closed dies:
a) in a horizontal forging machine; b) in a press; c) on a hammer

Drop-forging with formation of flash is also called open-die forging (see Figs. 266 and 267). Drop-forging can also be effected in *closed dies*; when forging in these dies no flash will be formed if the volume of metal required for making the forging is accurately calculated. For this reason, drop-forging in closed dies is also called flashless forging (Fig. 268).

Open-die forging is more commonly practised than forging in closed dies, the latter being practised for producing forgings up to 100 kg in weight (Fig. 268), whereas forgings up to 1 ton can be produced by the open-die method. Open-die drop-forgings are produced in hammers and presses, while closed-die forgings are made in forging presses and horizontal forging machines and, more rarely, on drop-forging hammers.

As regards the forging of the lever shown in Fig. 267, the stock for the forging is formed in a steam hammer. But it can also be forged as follows: the stock can be rough formed in the so-called preliminary die (or impression) and then transferred for finish forging into the finishing impression of the die. The gear blank and lever which have just been discussed are drop-forged in *single-impression dies* (see Figs. 266, 267). However, many forgings have to be stamped in multi-

impression dies, i. e., in dies having several impressions. Such dies have two types of impressions: 1) preliminary impressions, designed for preparing the stock for the final forging operation and 2) finish forging impressions in which the final forging operations are effected. *Preliminary* impressions, in their turn, are classified as fuller,

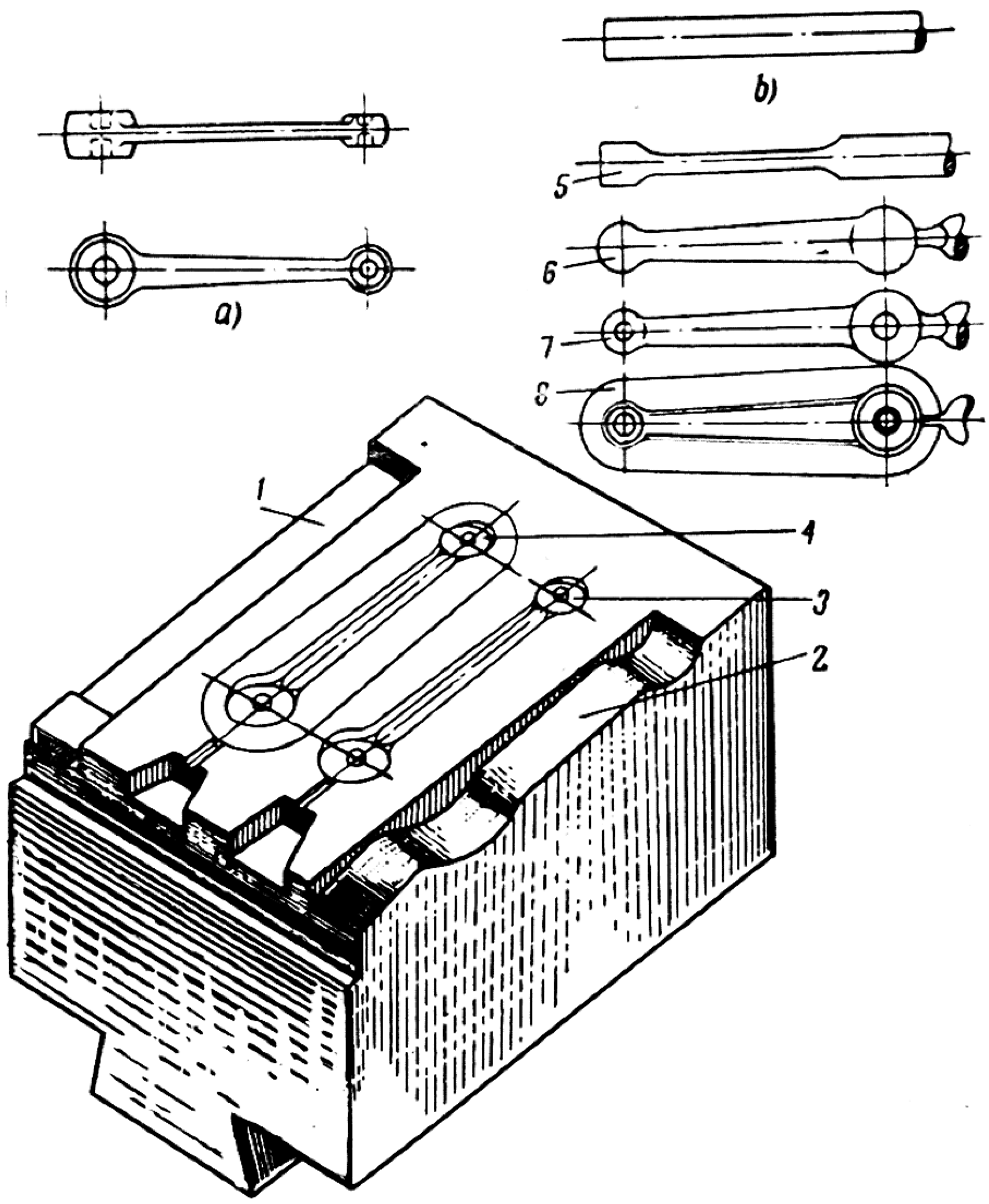


Fig. 269. Multiple impression die for drop-forging connecting rod (a) from stock (b):

1) edger; 2) bender; 3) blocking impression; 4) finish impression; 5, 6) stock after forming in preliminary impression (1 and 2); 7) forging after blocking impression (3); 8) forging after finish impression (4)

bending, edger, and blocking impressions. The fuller impression is used in drop-forging when it is required to reduce the cross-section of a portion of the forging stock between the ends of the stock; the bending impression is used when drop-forging bent work. The shape of this impression must correspond to the shape of the bend in the work. Edging impressions (edgers) are designed for distributing the metal in the general proportion of the shape to be forged; fullers—

when it is required to reduce a portion of the stock, as for instance, when making the reduced central section of the lever shown in Fig. 269. Benders are designed for forging work with projections, or bosses, as shown in Fig. 269, *a*.

Forging impressions are classified as rough and finishing impressions. *Finish impressions* are used only for forging simple work without large projecting parts, ribs, and sharp corners. In dies having only one finish impression the stock is transferred to them and given its final shape and dimensions immediately after being forged in the pre

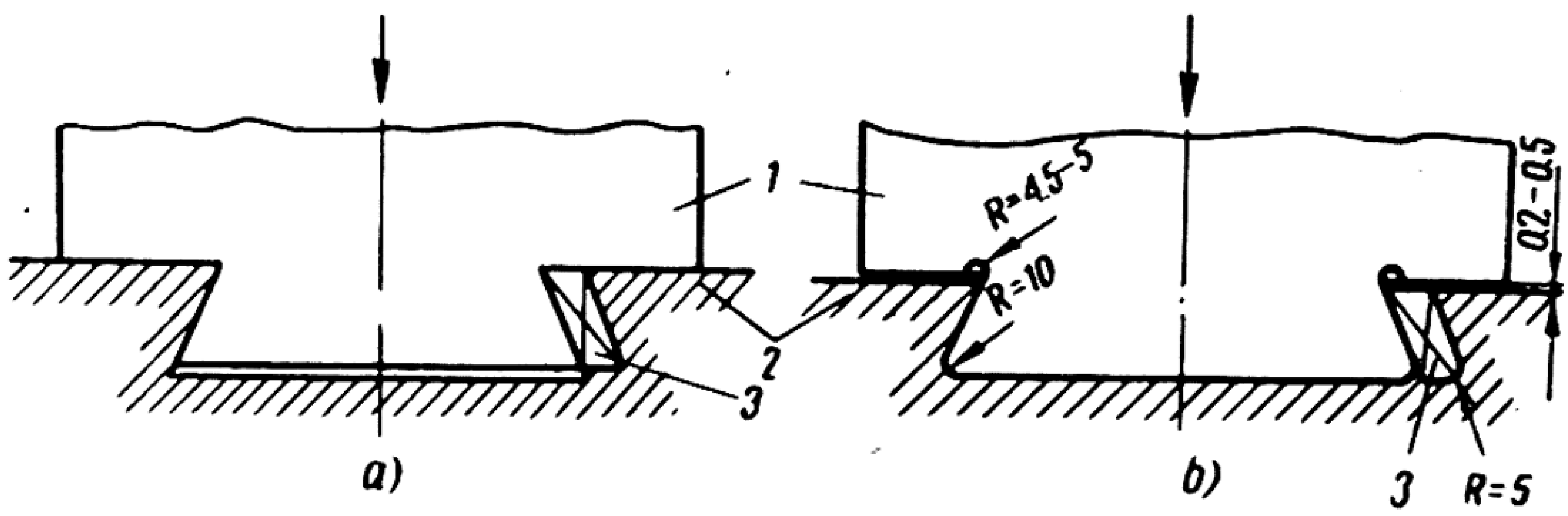


Fig. 270. Design of dovetails of die, and attachment of die:
a) incorrect design of dovetail and incorrect attachment of die corners (not rounded off); b) correct design of dovetail and attachment of die (corners rounded off)

liminary impressions. *Rough impressions* are employed for rough forming the shape of the forging; flash is formed in these impressions. Sometimes the flash is trimmed (cut off) before the unfinished forging is transferred to the finish impression.

It is not advisable to use dies with only one finish impression, as they are liable to rapid wear (their dimensions alter considerably and they have to be remachined). It is always better, even when only simple forgings are being made, to rough forge them in the preliminary impression before transferring to the finish impression.

Dies are made with dovetails and keyways (as shown in Fig. 270) for attaching them to the head of the ram and the anvil block. *Dovetail 1* of the top die is inserted in the grooves of the ram head and of die holder *2* and secured by keys *3*. Key *3* must be made so that it contacts the entire surface of the dovetail (Fig. 270, *b*). The grooves in the die-holder and ram head, together with the keys, prevent transverse displacement of the die. The locking pins, as shown in Fig. 271, are used for preventing longitudinal displacement, or shifting, of the die.

Die Maintenance. Dies are very expensive tools. To justify their high expense, it is necessary for them to be capable of forging the maximum quantity of forgings, and for this they must possess a very long life. Correct maintenance is one of the chief methods of increasing die life. The main rules for die maintenance are the following.

Before commencing work:

1) Make a thorough inspection of the die: make sure that it is absolutely free from damage, cracks or dents; immediately report to the foreman any defects discovered;

2) Install the dies exactly in position with the aid of the installation square; if the die has a lock, see that both dies close freely when the ram is lowered;

3) See that the die is properly installed; never use shims or gaskets; never permit the die to bear on the dovetail shoulder (Fig. 270, *a*), as this may result in its breakage;

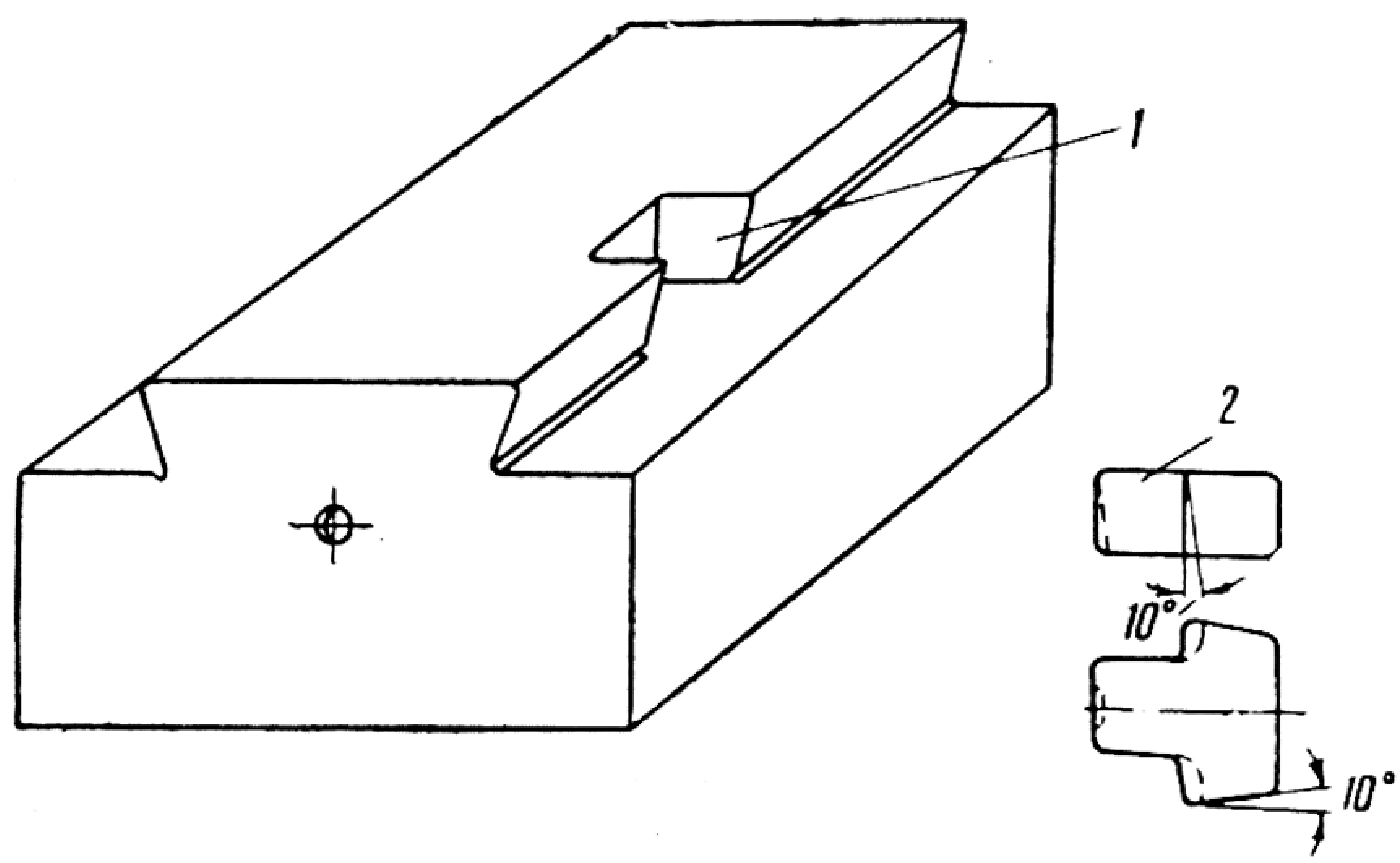


Fig. 271. Die secured against longitudinal displacement:
1) keyway in dovetail; 2) locking pin

4) Secure the die firmly by driving the keys into place with heavy blows of the sledge-hammer;

5) Check the installation of the dies by the match marks or with a trysquare; in the case of any misalignment (planes of dies out of parallel) of the dies, adjust them with the aid of the side keys;

6) Warm the dies to a temperature of not less than 150-200°C by packing them with hot pieces of metal or other means.

During operation:

1) See that the dies are securely attached and check the keys every half hour;

2) Do not allow any heavy idle blows of the top die against the bottom die; this may result in breakages of one or both dies;

3) Do not forge metal which has cooled below the permissible minimum forging temperature;

4) Before starting to work, always remove scale from hot stock;

5) Never permit the dies to reach a temperature above 400°C; should they become overheated, cool them with compressed air;

6) Grease the dies before each new forging operation;

7) On the discovery of cracks, however small, in one of the dies, stop work immediately and have the cracks removed.

After completion of the work:

1) Blow all scale and dirt from the faces of the dies with compressed air or steam;

2) If operations with the dies are finished: a) remove the dies from the hammer or the press; b) wipe the die impressions and faces with clean rags; c) grease the impressions and faces with solid oil; d) place the dies to their proper storage place.

Making Dies. At present the following types of die are manufactured: cast iron, and cast and forged steel dies.

Cast iron dies are employed exclusively for the production of small quantities of press forgings. Their advantage lies in their low cost and simplicity of manufacture: but they wear very rapidly, particularly as a result of impacts.

Dies of cast steel are very seldom employed, as the surface of cast steel is usually very porous and, moreover, difficult to machine. Their life, too, is very short, and for this reason they are employed for the production of small lots of forgings only.

For large-scale production, dies of forged carbon or alloy steels are employed exclusively. Carbon steel dies are employed for the production of a comparatively small quantity of forgings; alloy steel dies are generally used for large-scale production of forgings. The most commonly used die steels are: chromium-nickel, chromium-molybdenum, chromium-titanium and chromium-tungsten steels.

The first step in the manufacture of a steel die is the forging of the stock, or die block, as it is called. Die-steel ingots are first cogged in a press, forged, the head discard cropped off, and the ingot is then cut to the specified die-block dimensions. The die blocks are then heated to the required temperature and forged on all sides in a hammer or a press, upsetting alternating with reducing. This method of forging is practised in order to forge the steel thoroughly throughout its entire mass and to ensure uniform mechanical properties of the steel in all directions. After forging, the die blocks are annealed and machined on planing machines, milling machines or lathes. Nowadays impressions are made in die blocks by special machines, called die sinking machines, which operate with the aid of a master block or template. After the finish impression has been made, the top and bottom dies are clamped together in the position they will assume in operation and a cast is made by pouring molten lead or saltpetre into the finish impression; this cast is carefully measured and checked; the results of the measurements and checking indicate whether the impression has been properly machined. The dies are finally checked by making trial forgings in the hammer or press. After machining, the dies are heat treated, i. e., they are hardened, annealed, and then finish machined.

The method described above for the manufacture of dies is an exceedingly lengthy process and is not suited to their mass production.

For this reason, the manufacture of die blocks with *insert dies* is becoming more widely employed; these are much cheaper than dies made out of solid blocks.

Insert die blocks are of comparatively small dimensions (Fig. 272) and consist of insert dies *2* inserted into the master die blocks *1*.

The use of insert dies leads to a considerable economy in the use of expensive alloy steel, since alloy steel is used only for the insert die, which is relatively light; the die blocks are made of less expensive carbon steels. Another advantage of insert dies is that after they are

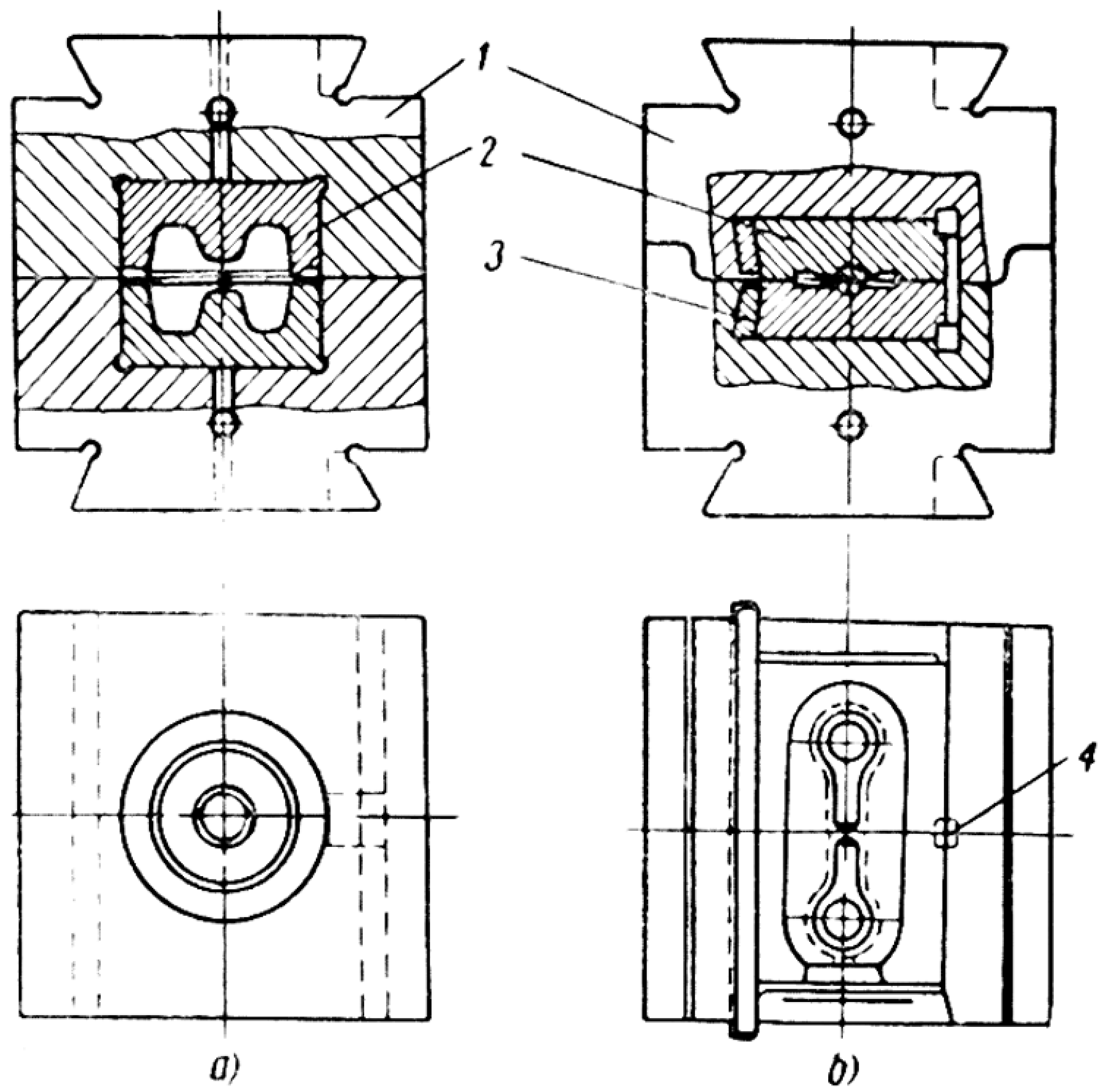


Fig. 272. Die with inserts:
1) die block; 2) insert die; 3) key; 4) insert die locking pin

worn out, they can be easily and quickly replaced in their blocks. Insert dies can be secured in their blocks by one of two methods: by shrink fitting, as shown in Fig. 272, *a*; or with the aid of keys (Fig. 272, *b*). Shrink fitting gives the best results.

DROP-FORGING METHODS

Two methods of drop-forging are practised: drop-forging in single-impression, and multiple-impression drop-forging. *Single-impression drop-forging* consists in forging the work in one (finish) forging impression. Here the preliminary operations (edging, bending, reducing, etc.) are carried out on other equipment: *forge hammers*, forging rolls, etc.

In *multiple-impression drop-forging*, all the impressions, from the preliminary to the finish impression, are contained in one set of dies,

and the forging process is carried out on one hammer only. *Drop-forging by steps* (passes) is only a variety of the multiple-impression process, this process entails several sets of dies for forging the work. In this method, the forging is conducted on several hammers, each of which is equipped with a different set of dies designed for one definite operation. Usually the stock is heated only once and then transferred from hammer to hammer without reheatings. This process of multiple-impression drop-forging is widely practised in the large or mass-scale production of forgings, as it is more productive and permits the organisation of flow lines for the production of duplicate forgings.

As an example, let us take the process of drop-forging the *connecting rod* in multiple-impression dies shown in Fig. 269, *a*. The connecting rod will be forged from a round stock *b* in the following sequence: it is first drawn in a fuller reducing impression *1* so as to leave a definite volume of metal at its end for forming head *5* of the rod; in impression *2* the stock is given the approximate shape *6* of the forging, having a sufficient volume of metal at the ends for forming the heads of the connecting rod; in blocking impression *3* the forging is given its rough shape *7*, while its final shape *8* is given in finish impression *4*. Blocking impression *3* is designed for transforming the stock, which until then had only a simple shape, into a more intricate shape approximating that of the finished forging. The use of shaped rolled sections for stock obviates the necessity for these preliminary impressions. The rough impression facilitates drop-forging in the finish impression, reduces the amount of metal wasted as the flash and prolongs the life of the finish impression, which is more susceptible to wear than the others.

ORGANISATION OF THE WORKING PLACE, AND LABOUR SAFETY RULES

The following chief safety engineering rules must always be observed when operating drop-forging hammers. Before commencing work, it is always *necessary*:

1) To see that the equipment is in order and that it is properly lubricated; to check the dies; to clean them from scale; to warm the dies and piston rod to 100-200°C;

2) To select all tools, tongs, sledge-hammers, etc., which may be required during work;

3) To check the compressed air and steam lines; to see that the hammer has the proper grade of lubrication in sufficient quantity;

4) After reading the technological process chart, to see that the necessary quantity of stock is at hand, and that it is of the proper quality;

5) To see that the furnace is properly charged with metal and that the stock in the furnace is heated to the specified temperature;

6) To put on the proper working clothes and protective devices (goggles, gauntlets, etc.) according to existing safety rules.

During operation:

1. Before placing the heated stock on the bottom die, remove all scale from its impressions by blowing it with compressed air or, in the absence of compressed air, by brushing with a birch brush; scale must never be removed with the gauntlets.
2. Never permit heavy idle blows of the top die to take place: should this be necessary, always place a wooden block between the dies.
3. Never forge burnt steel or steel whose temperature has fallen below 800-750°C.
4. Never allow the dies to be heated to temperatures above 400°C; cool them with compressed air or with a lubricant such as, for instance, a salt solution. Do not use masout, as this may lead to the development of cracks in the die impressions.
5. Never place your hands or any foreign object in the zone of travel of the ram if the latter has become loose, until the hammer has been stopped and the steam cut off.
6. Always hold the tongs during work so that their handle is at an angle to your body, and not directly in front of it.
7. Use each impression of the die exclusively for the purpose for which it is designed; always see that the stock is properly placed in the impression.
8. Take great care to keep the jaws of the tongs away from the top die.
9. On no account lower the ram below the safety mark.
10. During intervals in operation, always put the ram in its lower position and cut off the steam.
11. During work, periodically check the position of the die block with a spirit level in order to prevent the possibility of its misalignment.
12. Never allow the working place to become littered with forgings and scrap; always place them in their respective tote-boxes, and remove the boxes periodically.
13. Periodically check the forgings as they come out of the dies; should any defects be discovered (misalignment, pitting, laps, cold shuts, etc.) stop work, ascertain and eliminate the cause of the defect.

After completion of work:

1. Clean all scale from the die faces with compressed air or other means.
2. Put the working place in order and put all tools and fixtures in their proper places.

3. If the dies are no longer to be used for forging, remove them, clean off all dirt and scale, grease their faces and impressions and have them stored.

When operating power-driven presses, the following safety engineering rules and regulations must be observed.

Before commencing work:

1. See that the equipment is in proper condition and that it is properly lubricated; clean all dirt from the table and slide of the press.
2. See that the dies are properly and reliably secured in the press.
3. See that the necessary quantity of stock has been delivered to the press, and that it meets the specifications.
4. Prepare all tools and fixtures which may be required during work.

During operation:

1. See that the starting gear is in proper condition; at the slightest sign of trouble, stop work immediately and report to the foreman.
2. Use dies only for the purpose for which they are designed.
3. Never permit any foreign pieces of metal to fall between the dies.
4. During operation, always make sure that the dies are firmly secured; should they become loose, stop work immediately and report to the foreman.
5. See that the drive belt is always in good condition, and taut.
6. See that the brake functions properly, i. e., that the slide halts immediately on reaching its extreme upper position; should the brake get out of order, stop work immediately and report to the foreman.
7. See that all parts of the press are properly lubricated.
8. Never allow forgings and scrap to accumulate on the press table; always store them in their proper place.
9. Before starting the press, keep your hands clear from the working parts of the dies.

On completion of work:

1. Stop the press.
2. Remove all tools, fixtures, forgings and scrap and put them in their proper places.
3. Clean all parts of the press from dirt and wipe them with clean rags.
4. Grease the dies.
5. Tidy the working place.

Accidents are liable to occur during the operation of drop-forging presses from the following causes: a) inserting or withdrawing the work from the press by hand (this should be done with tongs, pincers. etc.); b) when extracting a forging which has stuck, restarting the press unintentionally if the press operator has not removed his foot from the treadle; c) carrying out work without protective devices, guards, etc.; d) the accidental switching-on of the press by an unauthorised person or by an object falling onto an unprotected treadle.

Safety during forge press operation can be *ensured* by observing the following rules:

1) The use of forging presses of rational design;

2) The employment of special safety devices and fixtures for feeding stock and withdrawing forgings;

3) The use of dies which meet all the safety engineering specifications;

4) Rational organisation of the working place; when working, it is highly important to observe the following rules: a) sit on a convenient chair—this will reduce fatigue; b) arrange the stock, forgings, scrap, tools, auxiliary materials correctly at the working place; c) always remove everything which will not be used during the course of work;

5) The observance of all sanitary and hygienic rules, such as: a) keeping all aisles and gangways clear of stock, forgings, waste metal, croppings, boxes, etc.; b) keeping the working place clean and tidy—by systematically removing all dust, dirt, etc.; c) proper illumination of the working place; not only the press and dies must be sufficiently illuminated during the day, but all aisles and gangways around the press also; artificial illumination must include as well as the general source of light, local illumination to the rear of the operator; d) wearing special working clothes which will not interfere with the execution of operations on the press;

6) The proper and timely instruction of the workers as regards the operation of the press, safety rules, etc.

THE DROP-FORGING TECHNOLOGY

The technological process of drop-forging includes the following *operations*: 1) cutting the stock to size; 2) heating the stock; 3) stamping; 4) trimming (cutting off flash), and 5) straightening. This sequence must be observed both when forging in multi-impression dies and by the flow method. If the drop-forging process is conducted by the combined method, the stock must be forged in a smith hammer after the second operation (heating), reheated and only then drop-forged.

Standard rolled sections and special rolled sections can be used as stock for drop-forgings. The use of special sections of definite shapes and dimensions is particularly advantageous in large-scale and mass production. These sections are rolled to correspond to the shape of the finished forging, thus obviating the necessity for intermediate operations preceding the finish forging operation in the finish impression: their use also results in a considerable saving of metal.

Sometimes parts of grade Ст. 3 and Ст. 4 steel, which are not designed for heavy duty, are stamped from cast steel blanks. Usually these

blanks are cast in such shapes so that they can be finish forged directly in the finish impressions of the dies. The use of cast steel blanks for drop-forgings greatly simplifies the production of intricately shaped forgings without resorting to the use of expensive multi-impression dies. When drop-forging cast steel forging blanks, casting defects, such as bubbles, cavities, etc., are usually squeezed out. Nevertheless, it is cheaper to use rolled stock for drop-forgings; rolled stock of standard and special section is delivered as bars from 3 to 9 metres long, most commonly, in 6 metre lengths.

The *first operation* in the drop-forging shop is cutting the bars into stock of the requisite length. In mass and large-scale drop-forging shops, stock is cut to length in special bar- and billet-shearing departments; individual and small-scale drop-forging shops, however, are usually not equipped with such departments, and the stock is cut to length on the main equipment of the forge shop.

Practical experience of the most advanced drop-forging shops shows that every forge shop, whether engaged in individual or large-scale production, should be equipped with a bar- and billet-shearing department, as this is particularly important from the point of view of organising production and economising metal. Such departments must be equipped with all the necessary machines, and all operations must be mechanised. The bar and billet departments must be designed, not only for cutting rolled stock to standard lengths, but also for: reducing the surplus lengths to smaller sections in hammers or in presses; preparing, whenever possible, drop-forging or hammer-forging croppings for further utilisation as stock for other forgings; sorting forging croppings into their respective grades, and for other miscellaneous work.

The various means of cutting stock to length are: a) cutting with shears; b) breaking in cold breaking fixtures; c) cold saw cutting; electric saw cutting, and d) gas cutting.

Shear Cutting. The most general method of cutting stock employed in mass and large-scale production forge shops is cutting it with shears or breaking it in cold metal breaking fixtures.

Shears are classified according to design into disc, lever and guillotine. The latter are employed for cutting sheet and plate metal. Shear presses are most widely used in forge shops. These presses operate on the principle of the crank press.

Shears are used for cutting both hot and cold metal. At present, shear presses are manufactured which can cut cold steel up to $300 \times \times 300$ mm in cross-section.

Shear presses are a highly productive form of equipment, as they make one cut with every stroke, and are capable of making from 3 to 32 strokes per minute; however, the greater the cross-section of the metal to be cut, the slower the speed of the shears will be. They can be

used for shearing stock from shaped rolled sections, but for this purpose they must be equipped with special fixtures.

Shearing cold metal is accompanied by considerable strains which are liable to develop cracks at the cut. For this reason, high-alloy and ordinary alloy steels must be heated to temperatures ranging from 350 to 700°C before shearing; the higher the temperature, the less force will be necessary to cut the steel.

Mild and medium carbon steels up to 200×200 mm in cross-section are usually cut cold. After being cut in shears, the ends of a piece of work will be rough; the greater the cross-section of the work and the higher the temperature of the metal, the greater the roughness of the ends will be. Because of this, the temperature to which the metal is heated before cutting will depend on the grade of steel and on the method of subsequent forging (stamping).

For subsequent upsetting the cut should be as straight and even as possible. This is not always attainable, especially when shearing high-alloy and high-carbon steels, since, in order to avoid the development of cracks at the shearing section, the steel has to be heated to very high temperatures (from 700 to 800 and even to 1,000°C); and at such high temperatures straight edges cannot be obtained by shearing. For this reason other shearing methods must be employed, such as shearing on cold saws or electric arc cutting, etc.

Stock is also sheared in crank-type and hydraulic presses with the aid of special dies and fixtures. Smith hammers and drop-forging hammers must not be used for cold shearing stock, as this operation is by no means safe.

Breaking Stock on Cold Bar-Breaking Fixtures. Stock can be broken in hydraulic and power-driven crank-type or eccentric-type presses. The process of breaking cold metal consists in placing the stock on two supports and bringing pressure to bear on it through a blunt blade at a point equidistant between the supports until the stock breaks.

Before breaking, the bar stock must be marked off into the required lengths, a notch 10-15 mm deep being made at each place where it is to be broken with a gas torch or, more rarely, with a cold cutting saw. The bar must be placed on the supports with the notch on its underside, exactly opposite the breaking rod (blade); moreover, the notch must be exactly in the centre between the supports.

The notch is necessary to ensure that the bar breaks exactly at this point without any visible deformation. Cold breaking of bars is widely practised since it is a highly economic shearing method, requiring no special equipment.

Another advantage of cold bar-breaking is that the quality of the metal can be inspected at the fracture, and this is very important in the production of high-grade alloy steel forgings. The minimum standard length of any section during cold breaking must not be less than

0.8 D, where D is the diameter, or length of opposite sides of the square of the bar.

Fig. 273 illustrates how a cold breaking fixture is installed in a crank-type press; the same method can be adapted for other presses. Cold breaking in forge hammers is prohibited, as this operation is considered to be very dangerous.

The *cold bar-breaking fixture* illustrated in Fig. 273, is designed as follows. Dovetailed plate *2* is secured to shoe *1* of the press by key *4* and dowel pin *3*, in the same way as dies are secured in hammers;

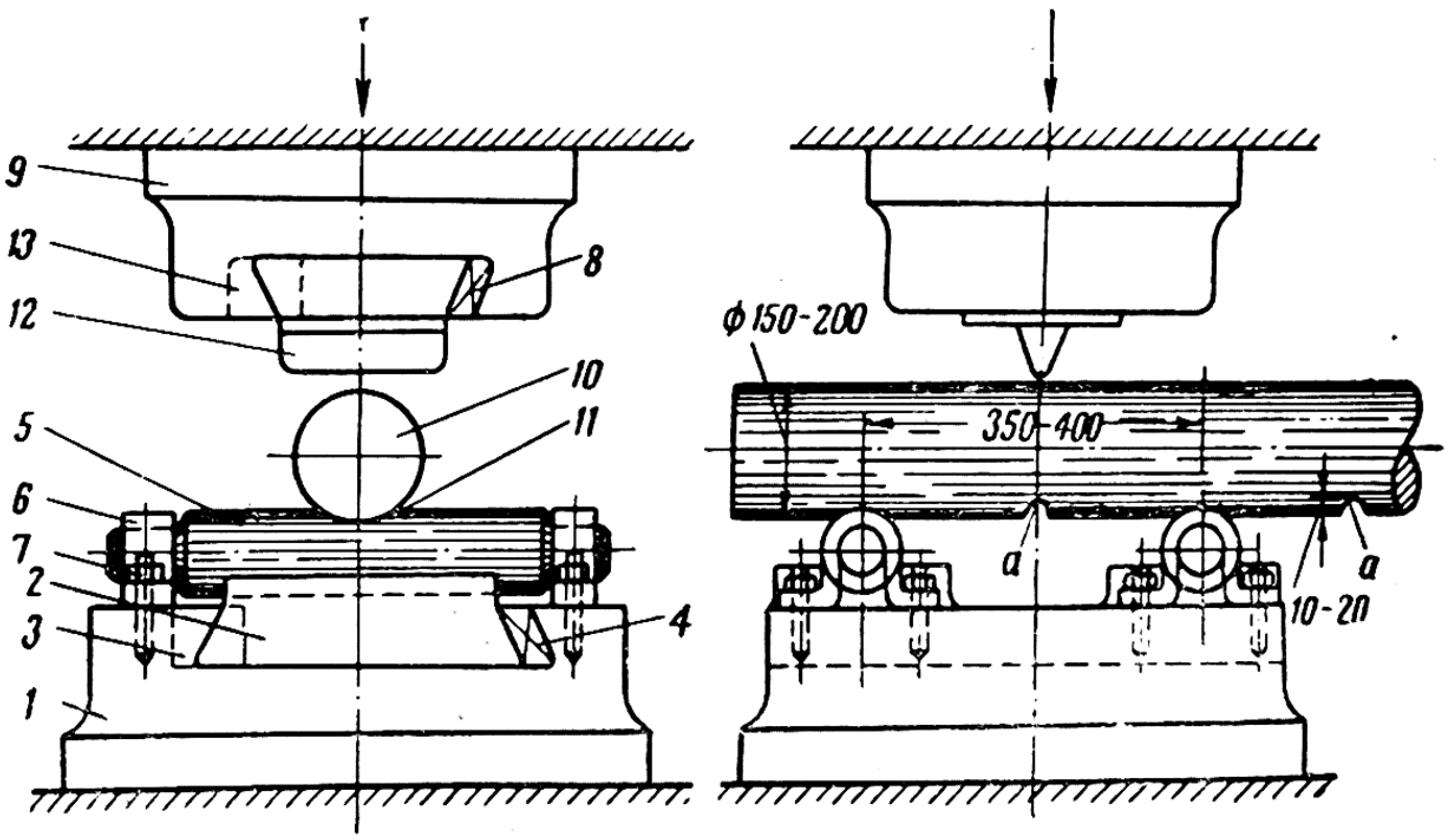


Fig. 273. Installation of cold bar-breaking fixture on press

the shoe is also secured to the press table through its dovetail. Two rods *5* are mounted across plate *2* in special grooves machined in the plate. Rods *5* are secured to shoe *1* with the aid of shackles *6* and bolts *7*. Shearing blade *12* is attached to the top travelling shoe *9* by means of its dovetail, key *8* and dowel pin *13*. Bar *10*, previously marked out and notched to length (notch *a*) is placed in groove *11* of rods *5* so that the centre of blade *12* is exactly vertically over that of notch *a* of the stock. The bar is broken by the pressure of blade *12*. After the blade has contacted the metal only a comparatively short stroke of the press—not more than 15-20 mm—is required to break a bar in such a fixture.

Cutting Stock on Cold and Electric Arc-Type Saws. Cold saws are employed for cutting stock into precise lengths, with square ends, and also for cutting short lengths from billets of large cross-section, i. e., when the length of the stock is less than 0.8 of the diameter or thickness of the billet. Cold saws are not very productive, and for this reason are not employed on a large scale in forge shops.

Electric arc-type saws are more than ten times productive than conventional saws.

Of great interest are *electric arc-type saws* for cutting metal, particularly for cutting high-alloy steels and extra hard alloys, which are usually cut only with special hard-alloy tools. The cutting speed of these saws is practically independent of the mechanical properties of the steel being cut.

These saws consume less power than cold cutting saws and produce much cleaner cuts. Since the cutting tool of the arc-type saw is a very thin disc—from 2.5 to 3 mm thick, the loss of metal as kerf in electric arc cutting is insignificant.

Electric arc-type saws operate by generating a high temperature at the place of contact between a thin disc without teeth and the metal to be cut; the metal melts and, as the disc rotates at a high speed, it sweeps the molten metal from the cut in the form of sparks. Thus in these saws the discs are designed not for severing the metal, but for conducting electric current to the metal at the point where the cut is required, and for sweeping the melted particles of metal from the cut itself.

Fig. 274 shows an electric arc-type saw, in which electric current is fed to disc *3* through sliding contact *2* and a shaft from transformer *1* (see Fig. 274,*a*).

The discs are usually made of iron or steel plate from 2.5 to 3.0 mm thick. As can be seen from Fig. 274, *a*, disc *3* is rotated by electric motor *4* through a gear drive, at a speed of up to 2,200 rpm. Stock *11* to be cut is connected to transformer *1* by a return wire.

An electric current thus flows between the disc and the stock to be cut. When the rotating disc comes into contact with the stock, the electric current generates thermal energy raising the temperature at the point where the disc comes into contact with the bar stock, until the latter melts; as a result, the disc easily cuts into the metal and sweeps its melted particles away as sparks.

The mechanism of an electric arc-type cutting saw is mounted on cast frame *5* (Fig. 274, *b*), suspended from beam *10*. Electric motor *4* is mounted on bracket *7* which is hinged on axles *6* mounted in frame *5*. Disc *3* is rotated by the electric motor through a belt drive. Frame *5*, together with disc *3* suspended from hinge *6* is fed gradually by hand, with the aid of handle *8* towards bar *11* which is to be cut. Counterweight *9* on frame *5* facilitates the return of the frame to its original position.

Cutting discs can be made of any steel, as, for instance, grade Cт. 3 steel. Even when cutting high carbon steels, the wear of the disc is insignificant, since it contacts the cut (high temperature spot) for an exceedingly short period of time and, rotating at high speed, cools very rapidly.

Gas Cutting. Gas cutting consists in directing a jet of high calorie fuel (gasoline, acetylene, coke-oven gas, etc.) burning in a stream of oxygen to the point where the cut is required thereby heating it to above its melting temperature.

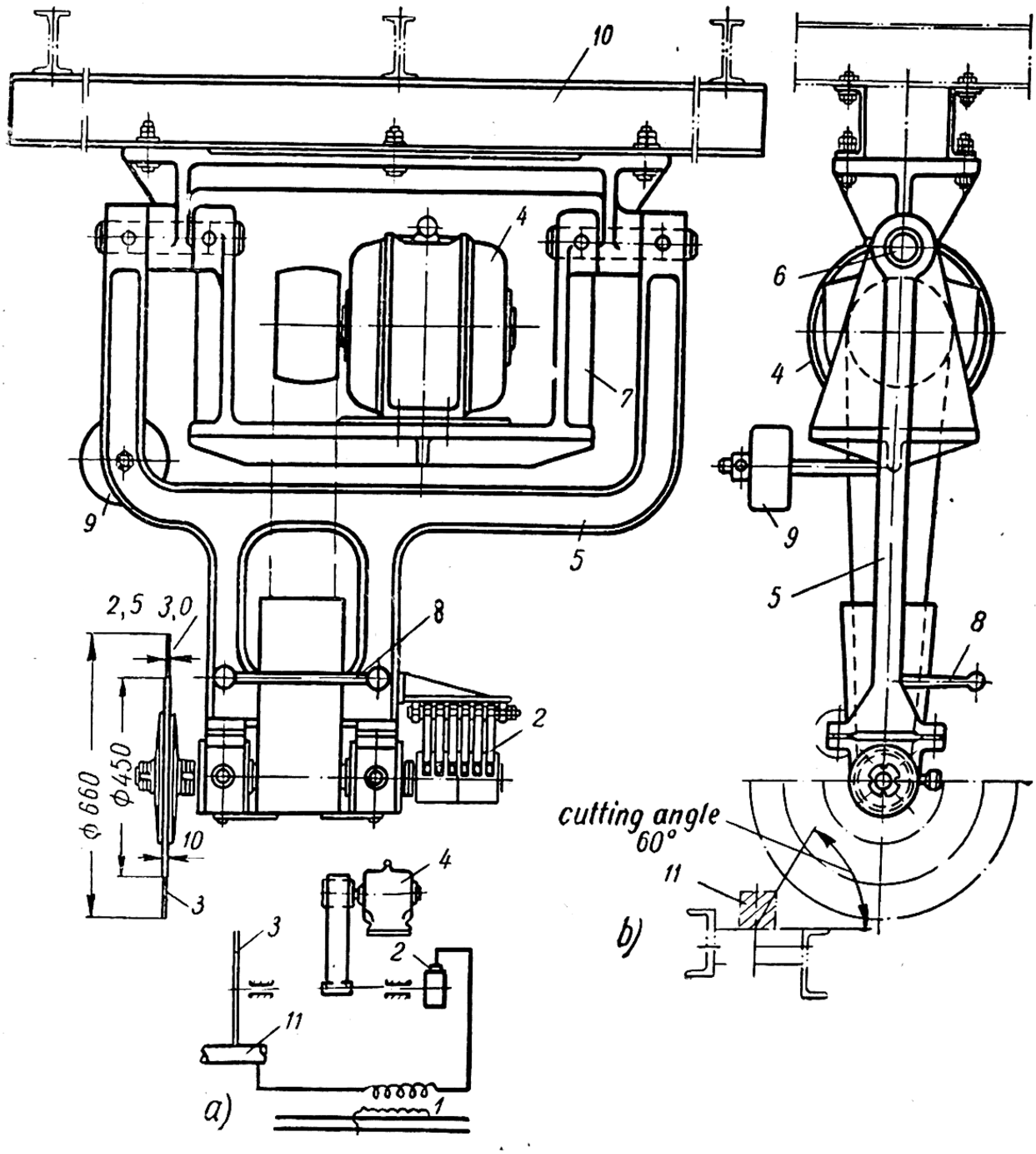


Fig. 274. Electric arc-type cutting saw:
a) gearing diagram of electric saw; b) electric arc-type cutting saw

Gas cutting is carried out with special cutting torches—gasoline, kerosene, or gas torches, depending on the kind of fuel used. Gas cutting is very frequently employed in forge shops for cutting thick plates and rolled shapes.

Heating Metal for Drop-Forging. Metal must be heated before drop-forging for the same reason as it has to be heated before ordinary hammer forging, i. e., in order to increase its plasticity.

As a rule, the productivity of drop-forging machines is greater than that of steam hammers. It often happens that the heating furnaces are unable to cope with the speed of the drop-forging unit (hammer or press), thereby curtailing its productivity; and this occurs even in spite of the fact that the productivity of the furnace should be not only at least equal to that of the forging unit, but even slightly in excess of it.

Two methods are usually employed for heating metal before drop-forging: flame and electric heating. Of recent years highly productive mechanised heating furnaces have come into wide use for *flame heating*.

The design of these mechanised furnaces depends on the character of the stock to be heated and also on the type of forging machines served by the furnace. Mechanised furnaces include continuous-type, pusher-type, rotary-type and conveyor-type furnaces.

Continuous-type furnaces are employed for heating relatively thick and long square and flat bars: in these furnaces the work is fed along the hearth from the charging to the discharging end. In conventional continuous-type furnaces, the stock is heated from one side only; but in the more modern designs higher productivity and uniform heating of the stock throughout its entire length is ensured by heating the stock from both sides; in addition, the work is made to slide through the furnace over water-cooled skidding tubes. To reduce the consumption of fuel required for heating the water in these tubes, they are heat insulated with a special refractory clay.

As can be expected, the productivity of the conventional type of continuous furnace is much lower than that of the modern type. While the weight of steel heated per square metre of hearth per hour in the latter furnaces reaches 500-600 kg and even 900-950 kg, that of the conventional continuous-type furnace is usually not more than 300-350 kg.

Rotary-type furnaces are employed for heating shaped stock of round section and short lengths which cannot be loaded in a pusher-type furnace. The main advantages of rotary-type forging furnaces as compared with continuous pusher-type furnaces are: 1) they take up from 20 to 30 per cent less floor space than continuous-type furnaces; 2) they can take stock of any shape. Rotary-type furnaces are particularly convenient for heating short stock, which can be loaded upright on the furnace hearth; in this position they will be licked on all sides by the hot furnace gases and will therefore be heated far more rapidly than otherwise.

Slot-type box furnaces and mechanised *conveyor-type furnaces* built with chains travelling outside the furnace, instead of inside the working chamber, are employed for heating the ends of rods and bars, for instance, before upsetting in horizontal forging machines.

Electrical heating for drop-forging is nowadays being increasingly widely used; this method has already been described in Chapter VI.

Scale is very detrimental both to stampings (forgings) and to dies, causing their rapid wear and destruction due to pitting, etc.; for this reason, scale must always be completely removed from the surface of the work before forging. There are many methods of removing scale: cleaning the stock with a jet of steam or compressed air; brushing; and finally *hydraulic* descaling. This last method consists in placing the heated stock from which the scale is to be removed in a chamber where it is descaled by the action of a jet of water under high pressure (120-150 atmospheres). Since the stock remains in the hydraulic descaling chamber for a very short time (1-0.5 second), it is not appreciably cooled.

Hot Stamping. Stamping when the stock is placed upright between the dies, is called *drop-* or *upset-forging*; stock for upset-forging is always calculated for one forging only. However, whenever the technological process permits, it is always more profitable to make stampings from stock calculated for several forgings, and when stamping heavy forgings, from stock calculated for two forgings.

When stock is calculated for two forgings, it must be turned round during the drop-forging operation, i. e., after first being stamped from one end, it must be turned and stamped from the opposite end. Stamping from stock calculated for several forgings has the advantage that less metal is wasted than when stamping from stock calculated for one forging only.

When only one forging is to be made from a piece of stock, a tonghold allowance 50-60 mm long must be left at one end of the stock; this tonghold, together with the flash, is generally lost as scrap. But, if correspondingly processed, it can be used for making other forgings of smaller cross-section. Nowadays stamping without tongholds is coming into wide use.

The technological process and forging methods must be selected with due consideration of the conditions in which the forged component will operate. As an example of the influence of the technological process of drop-forging on the quality of the finished component let us take the process of drop-forging a coupling hook.

Coupling hooks are important parts, subject to severe duty. For instance, a railway-car coupling hook has to withstand the tractive effort of the locomotive, and the safety of the railway traffic depends to a considerable extent on the strength of the hook. For this reason, the technological process of its manufacture must ensure its highest

possible tensile strength and it must be forged with due consideration for the direction of the fibre of the steel; on no account should the fibre of the metal be severed during the forging process, as this will considerably reduce the mechanical properties of the hook, making it much weaker.

Fig. 275 illustrates the process of drop-forging a coupling hook by the old method, in which cutting the fibre was unavoidable. In this

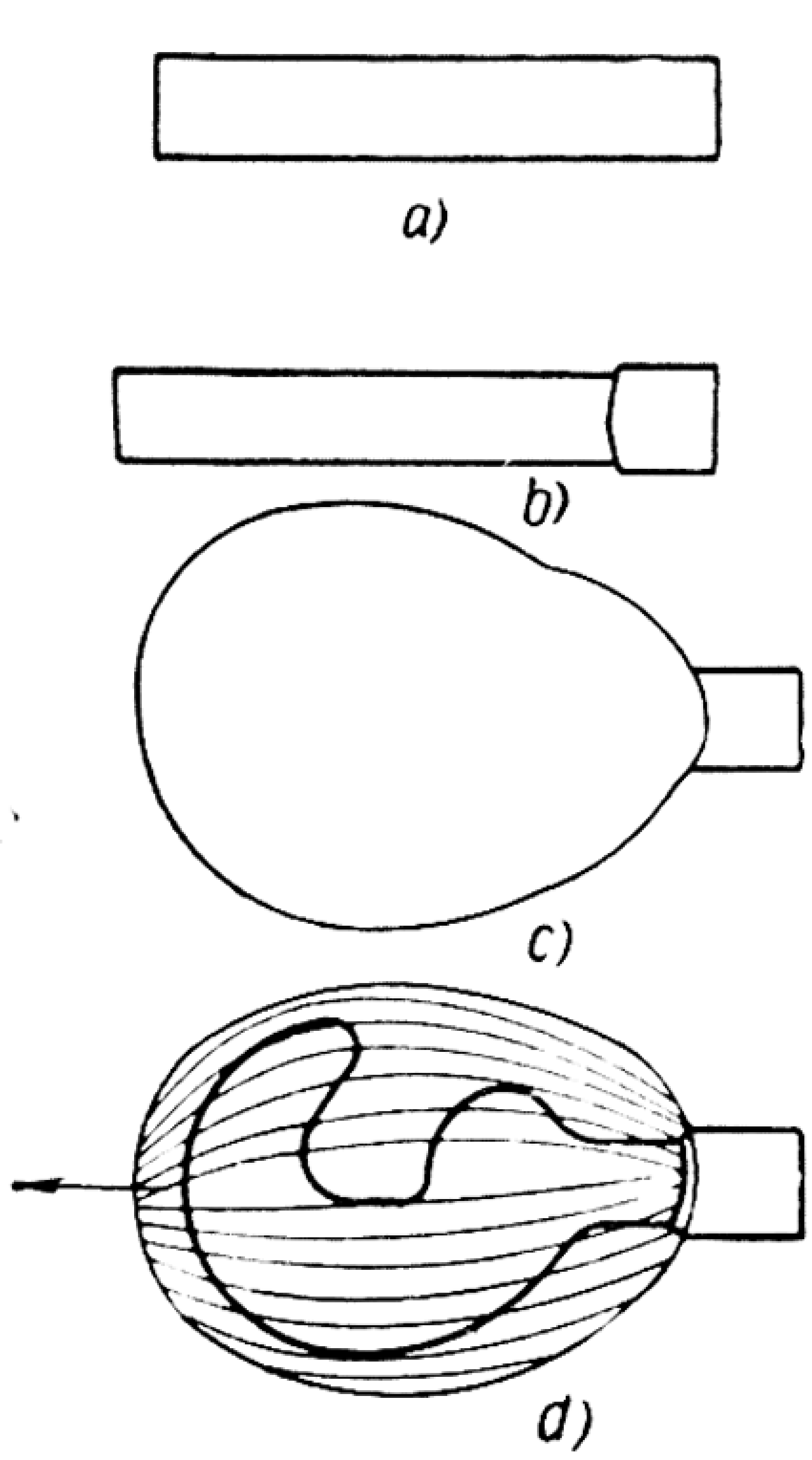


Fig. 275. Coupling hook drop-forged by old method:

a) stock; b) stock after drawing-out; c) head of stock flattened; d) head of stock after being stamped (1—direction of tractive effort)

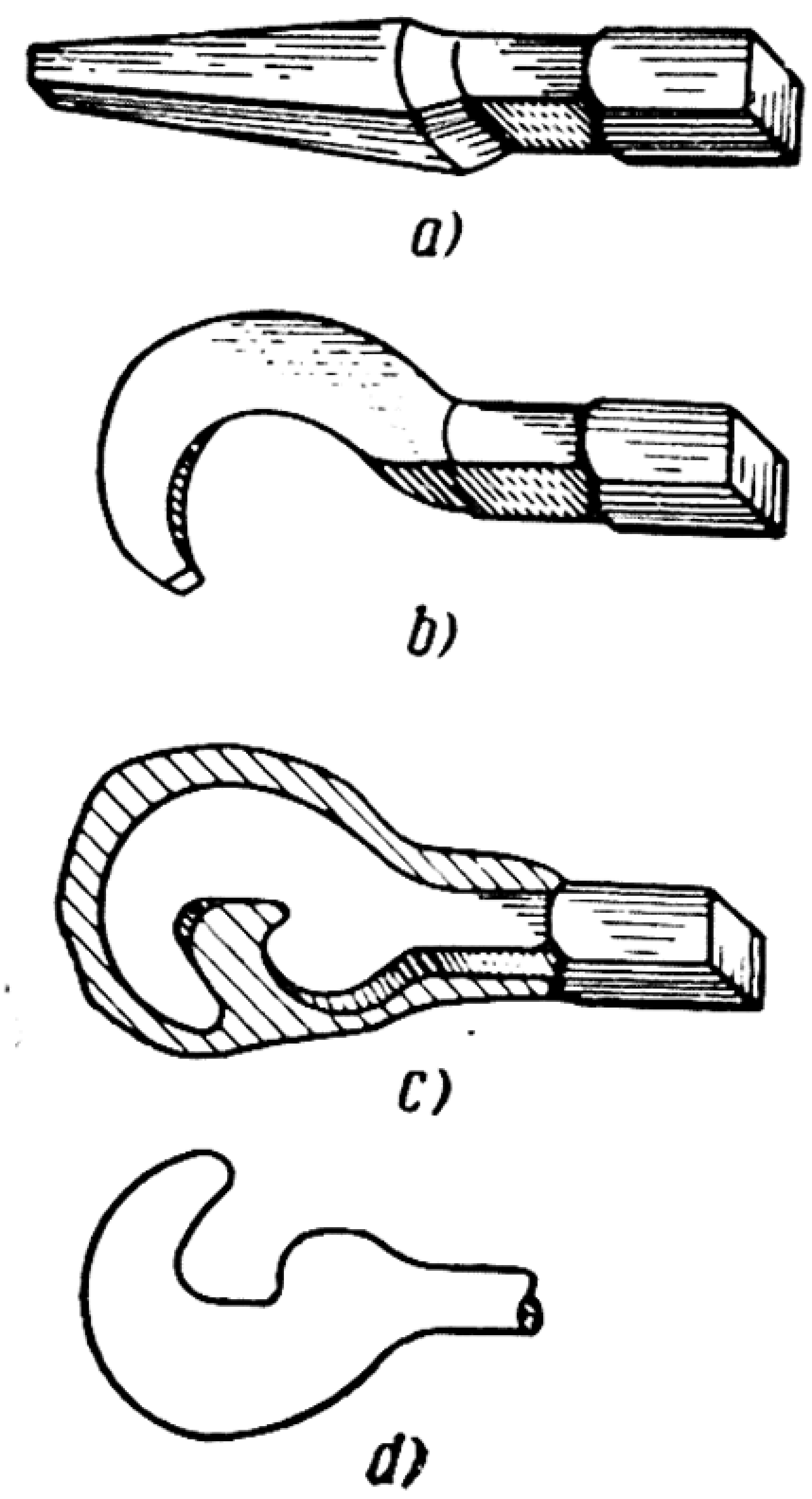


Fig. 276. Coupling hook drop-forged by new method:

a) drawing-out end of stock; b) stock bent to form head of hook; c) hook after being drop-forged without trimming flash; d) location of fibres in hook after drop-forging

case, the sequence of operations was as follows: 1) cutting the stock to length; 2) drawing-out the head under a steam hammer (Fig. 275, *b*); 3) flattening the head, as in Fig. 275, *c*; 4) forging in dies to the shape shown in Fig. 275, *d* and subsequently cutting out the jaw and trimming the flash in an eccentric trimming press. By this method of forging the hook the fibre of the metal is severed at the most dangerous section—at the nose of the hook; and, since the tractive effort is directed along, and not across the fibres, there is the danger that the hook will break at this point.

Fig. 276 illustrates the new technological process of drop-forging a coupling hook so as to ensure the proper disposition of the fibre. The

difference between this method and the former one is that after the first operation of drawing-out the head of the hook (Fig. 276, *a*), the hook is bent, as shown in Fig. 276, *b* and then stamped and trimmed, as shown in Fig. 276, *c*. As a result of this improved technology the direction of the tractive effort now coincides with that of the fibre, as can be seen from Fig. 276, *d*.

According to this technological process, the coupling hook is forged in three-impression dies. The first impression is designed for reducing the stock, the second—for bending, and the third—for finish forging. The mechanical properties of coupling hooks forged in such dies will be much higher than those of hooks forged by the former technological process.

The volume of metal required for drop-forging is calculated from the following formula:

$$V_{stock} = V_{forg} + V_{flash} + V_{sc}\ \text{cm}^3,$$

where V_{stock}—volume of stock in cubic centimetres;
V_{forg}—volume of forging in cubic centimetres;
V_{flash}—volume of flash in cubic centimetres;
V_{sc}—volume of loss due to scale in cubic centimetres.

When forging is executed in closed dies, the volume of the flash metal, V_{flash}, is not taken into consideration, as no flash is formed and consequently none has to be trimmed.

The volume of metal required to ensure a tonghold is then added to the calculated volume of the stock. For instance, if, according to calculations, the length of the stock is to be 600 mm, 50-60 mm are added to this length for a tonghold—thus making the total length of the stock 650-660 mm.

The volume of the forging, V_{forg}, is calculated from its drawing, and includes all allowances. The volume of the flash is calculated from the formula:

$$V_{flash} = pab\ \text{cm}^3,$$

where p—the perimeter of the forging along which the flash will be located in centimetres;
a—average width of the flash, in centimetres;
b—average thickness of the flash, in centimetres.

The dimensions of flash are determined from tables, and depend on the hammer and the forging method used. The volume of loss due to scale when heating stock in flame furnaces will be from 1.5 to 3.0 per cent and, when heating it by electric current, from 0.5 to 1.0 per cent of the sum of the volume of the stock and the volume of the flash.

When the volume of the stock is known, its length and cross-sectional area can be calculated. When calculating the cross-sectional dimensions of a piece of stock for drop-forging without upsetting, the

following rule must always be observed: the cross-sectional area of the stock must be 10-15 per cent greater than that of the finished forging.

Trimming the Flash. After forging in open dies, the flash must always be removed from the forging. Flash is removed, i. e., trimmed, in special trimming dies on crank-type or eccentric presses; the forgings can be trimmed with or without previous heating.

Forgings of aluminium alloys, copper, brass, bronze and of mild steel (grades 20 and 25) are usually trimmed cold; in these cases, trimming is a special operation, and is performed separately. The entire batch of forgings is sent simultaneously to the trimming press. Should straightening be required after trimming, it can also be performed without heating the forgings.

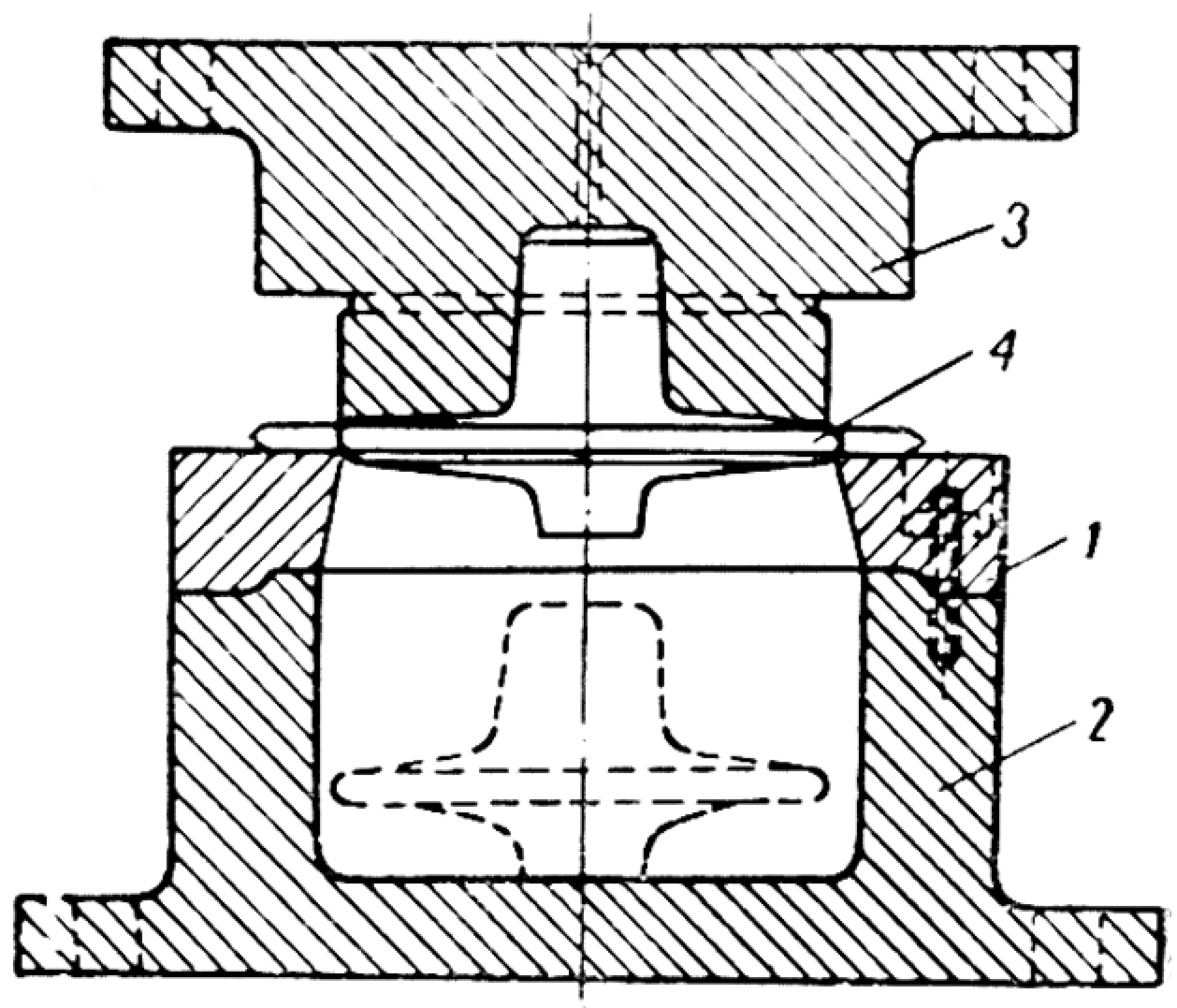


Fig. 277. Flash trimming die

Components of harder steels, as well as those of large dimensions, must always be heated before trimming and straightening. In these cases, the forging and trimming operations are closely connected, as all the work is, as a rule, executed in a single heating; the stamped forgings are transferred to the next unit (trimming press) immediately after the completion of the final forging operation, after which they are returned to the same hammer for straightening, without extra heating.

The *trimming die*, as illustrated in Fig. 277, consists of trimmer blade *1* and punch *3*; the trimmer blade is secured in a special pillow or shoe *2*. Shoe *2* is bolted to the table of the press, while punch *3* is attached to the slide of the press by means of its dovetail. The blade, which is made of tool steel, has a hole corresponding both in contour and dimension to forging *4* and, of course, to the finish impression of the forging die.

The punch is made to fit the trimmer blade with a clearance of 0.5 to 1 mm. To trim the flash, forging *4* is placed over the hole in the trimmer blade so that the flash serves as a support from which it is suspended. When the press is started, punch *3* descends and forces forging *4* through the hole; the flash will be cut off (trimmed), remaining on the top of trimmer blade *1* from which it can be removed, while the forging falls into shoe *2* and is removed through a hole in the shoe.

Straightening. After trimming, forgings may be slightly deformed (distorted), and must be straightened. This operation is performed on a hammer or in a special press immediately after the trimming operation. Straightening under the hammer is performed with one light blow in the finish forging impression of the die, or in a special straightening impression.

Examples of Drop-Forging Operations. Fig. 278 illustrates the technological process of *making a lever*, the forging stock being prepared in a smith hammer. The weight of the stock is 7.8 kg, that of the forging is 6.2 kg, the yield being 75 per cent. Material—grade Ст. 40 steel. The forging sketch is shown in Fig. 278, *a*.

The *technological process* provides for the following operations:

1) Inspecting stock: checking dimensions and accepting metal against certificate;

2) Cutting stock to length on shears (Fig. 278, *b*);

3) Hammer forging on 500-kg hammer (Fig. 278, *c* and *d*);

4) Accepting forged stock: a) forging in finish impression (Fig. 278, *e*); b) trimming flash (Fig. 278, *f*); c) bending in bending impression of die (Fig. 278, *g*). All these operations are performed on a 6.5-ton drop-forging hammer and in a 600-ton eccentric press;

5) Removing flash on floor grinding machines;

6) Marking;

7) Pickling in pickling baths;

8) Acceptance of forging by visual inspection and selective measurement.

The following tools will be used for the above operations: working (main) tools for the 2nd operation: shears; for the 3rd operation: flat top and bottom dies; for the 4th operation: forging and trimming dies; for the 6th operation: stamp, hammer. Auxiliary tools: for the 1st, 4th and 8th operations: folding rule, calipers; for the 8th operation: folding rule, calipers and template.

Forging temperature interval: for the 3rd operation: 1,150-750°C; for the 4th operation: stamping at 1,200-900°C; flash trimming at 800-750°C; bending at 750-700°C.

Fig. 279 illustrates the *technological process of drop-forging a handle*.

Weight of stock—1.31 kg; weight of forging—0.96 kg; yield—73 per cent; material—grade Ст. 3 steel. The sketch of the forging is given in Fig. 279, *a*. The process will consist of the following operations:

1) Inspecting stock: checking dimensions and accepting metal against certificate;

2) Cutting stock to length on shears (Fig. 279, *b*);

3) Drawing in 2-ton hammer (Fig. 279, *c*); drop-forging in 1-ton hammer (Fig. 279, *d*); trimming on 125-ton trimming press, and bending in 1-ton drop-forging hammer (Fig. 279, *e*);

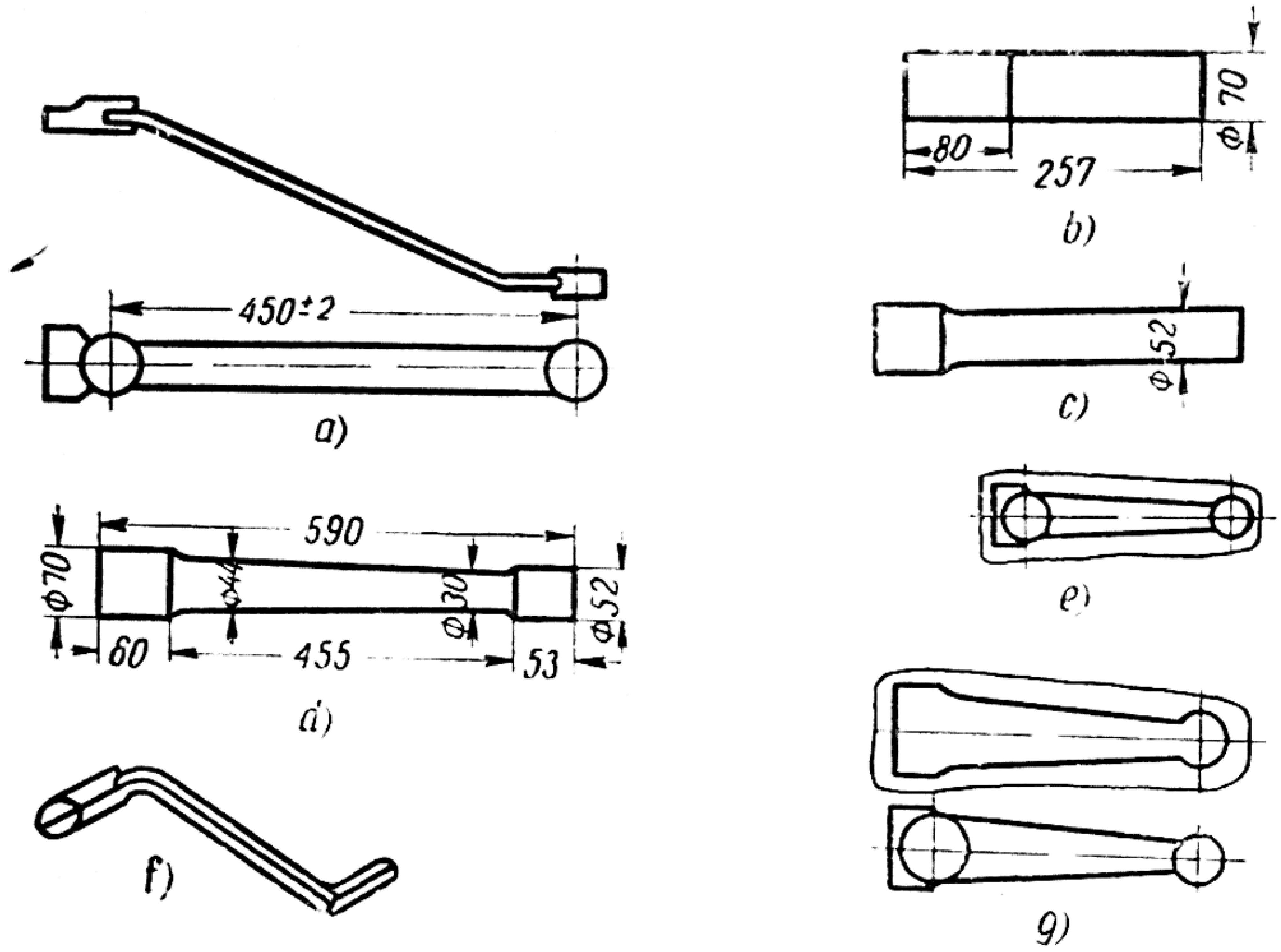


Fig. 278. Technological process of drop-forging a lever:
a) sketch of lever; b, c, d, e and f) sketches of passes in drop-forging lever

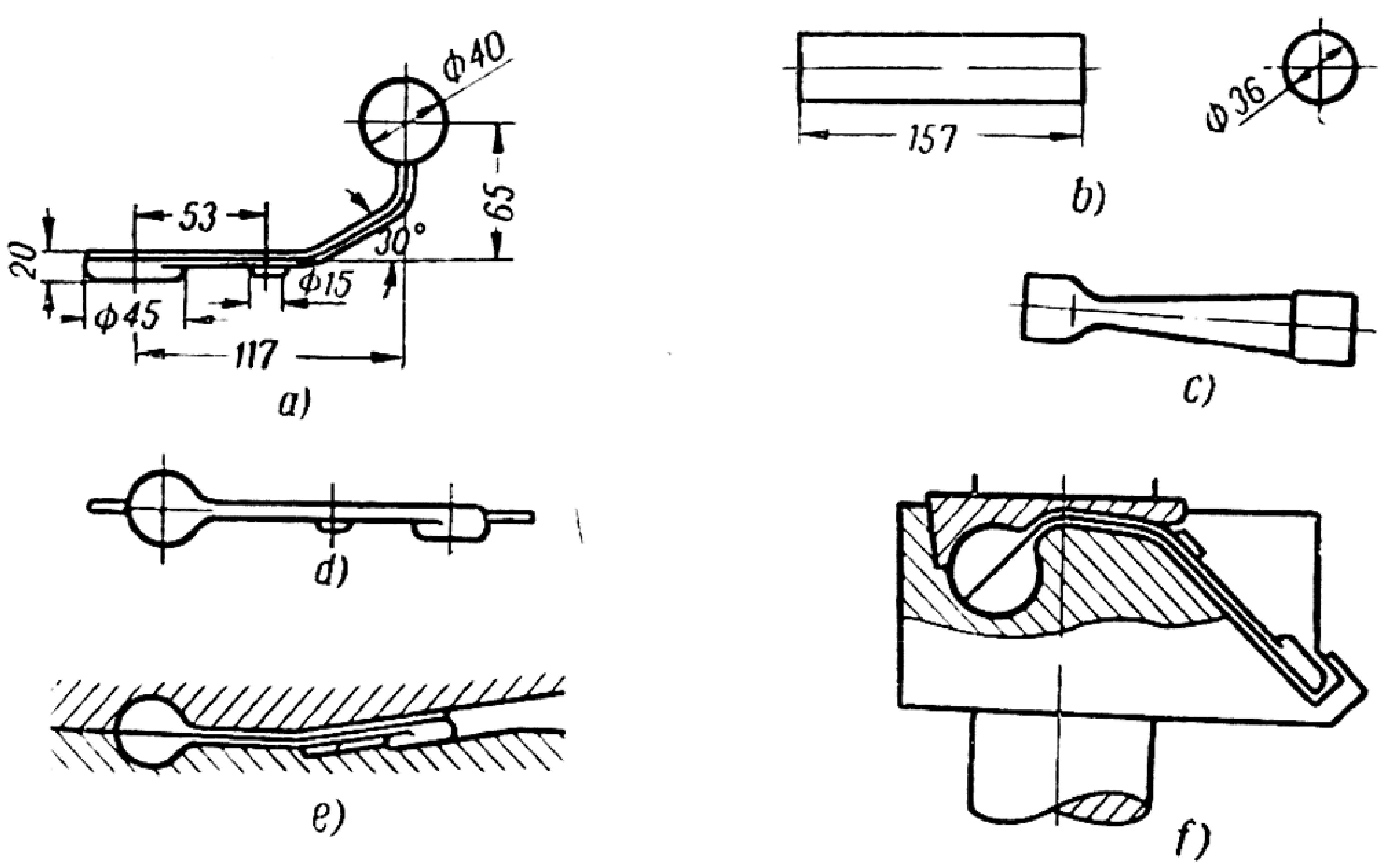


Fig. 279. Technological process of drop-forging handle:
a) sketch of forging; b, c, d, e and f) sketches of passes in drop-forging handle

4) Marking;

5) Bending in friction press between bending dies (Fig. 279, *f*);

6) Descaling in pickling baths;

7) Removing flash on floor grinding machine;

8) Acceptance (inspection) by visual examination, selective measuring and marking out.

Tools used for the above operations: working (main) tools for the 2nd operation—shears; for the 3rd operation—dies; for the 4th operation—hammer, sledge-hammer; for the 5th operation—bending die. Auxiliary tools: for the 4th operation—stamp; for all other operations—folding rule and calipers.

Forging temperature interval for all passes of the 3rd operation—1,200 to 750°C; for the 5th operation—900-750°C.

HORIZONTAL FORGING MACHINES AND THEIR OPERATION

Nowadays, horizontal forging machines are being increasingly widely used for drop-forging in closed dies and, more seldom, in open dies. Drop-forging in *horizontal forging machines* is mainly an upsetting operation. These forging machines possess the following advantages when compared with drop-forging:

1) The quality of the metal after forging in these machines is superior than after drop-forging in hammers or presses;

2) Drop-forging in forging machines is accompanied by little or no flash, whereas drop-forging in hammers is accompanied by the production of flash weighing from 10 to 75 and even up to 200 per cent of the weight of the finished forging;

3) Forging machines have a higher productivity, and their maintenance is much cheaper than that of drop-forging hammers;

4) Drop-forging in forging machines does not require forging drafts, which are essential for forging in hammers; this makes it possible to save metal and cut machining expenses;

5) When forging gear blank-type forgings with through or dead holes on drop-forging hammers, they are frequently produced without the holes, or with holes having considerable taper; this entails extra piercing or punching (sizing) operations; the accuracy of holes of forgings made in horizontal forging machines is much higher, thereby obviating the necessity for additional operations.

Fig. 280, *a* illustrates an example of a component forged on a drop-forging hammer, and Fig. 280, *b*—the same forging produced on a horizontal forging machine. The forging shown in Fig. 280, *a* has no through hole and, moreover, has been made with forging drafts; the forging shown in Fig. 280, *b*, produced in a horizontal forging ma-

chine, is made without forging drafts, and its holes are fully pierced; with this forging the consumption of metal and the machining expenses will be less than with the other.

The above-mentioned advantages of drop-forging in horizontal machines compared to drop-forging in hammers has led to a steady increase in their use. Today this progressive forging method is developing at an ever-increasing rate, particularly in mass and large-scale production.

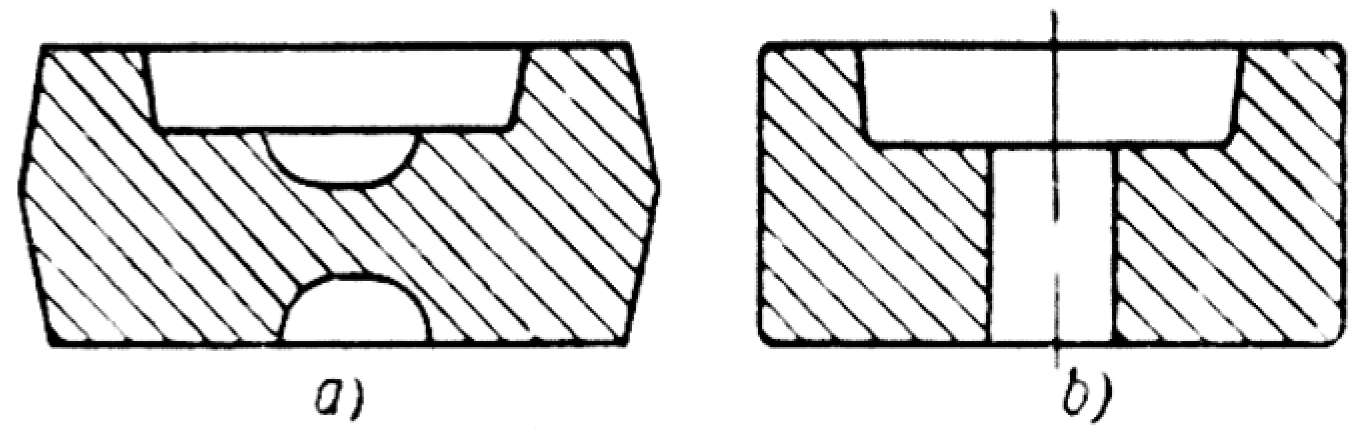


Fig. 280. Work forged in hammer (*a*); the same work upset in a forging machine (*b*)

Fig. 281 gives a diagrammatic illustration of *upsetting* in horizontal forging machines. Suppose that it is required to upset head *2* of the end of a piece of stock *1* (Fig. 281, *a*). For this purpose, a rod of the corresponding diameter is selected, one end of it is heated and inserted between dies *3* and *4* until it contacts stock-gauge *6*, as shown in Fig. 281, *b*. The dies consist of stationary die *4* and gripping die *3*, de-

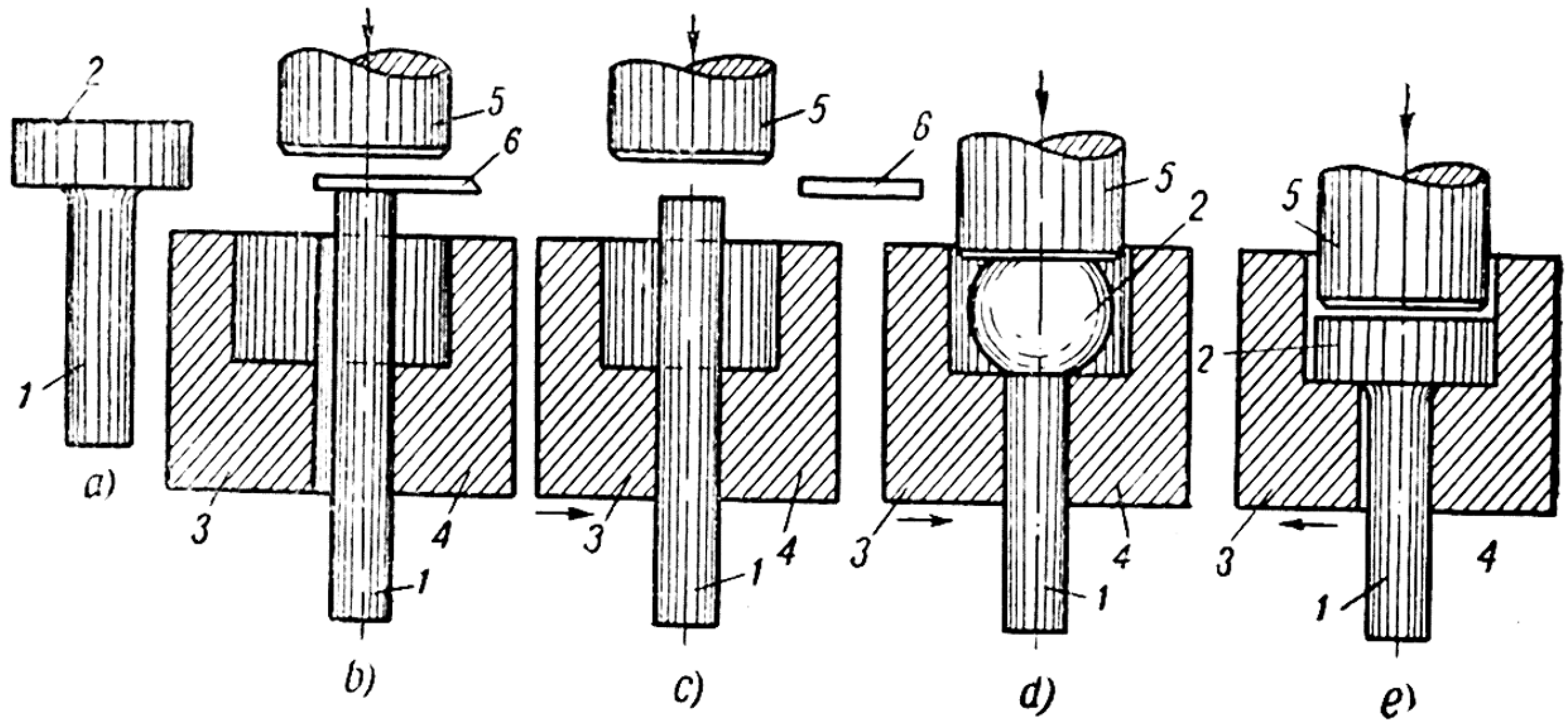


Fig. 281. Diagram of upsetting process in a horizontal forging machine:
a) forging; b) position of stock at starting of machine; c) upsetting dies closed and automatic stock-gauge retracted; d) end of upsetting—heading tool (5) and dies (3) return to original position

signed to slide towards the stationary die so as to grip the work firmly, and away from it to release the work.

Thus, as distinguished from forging hammers and presses, horizontal forging machines have two sliding tools—gripping die *3* and heading die, or punch, *5*; their movement is interconnected. After the stock has been inserted into the dies, as shown in Fig. 281, *b*, grip-

ping die *3* moves to the left and holds the end of stock *1* firmly against stationary die *4*; at the same time, automatic stock-gauge *6* moves aside, as shown in Fig. 281, *c*. Then heading die *5* presses the protruding end of the rod, thereby upsetting it until the metal completely fills the die impression, i. e., until end *1* is upset to form the required head *2*.

The beginning of the upsetting is shown in Fig. 281, *d*. After the head has been upset, heading die *5* and gripping die *3* return to their original positions, releasing the finished product from gripping die *3* (Fig. 281, *e*). Upsetting can also be performed in open dies, as shown in Fig. 282; this method, however, is very seldom employed, as it

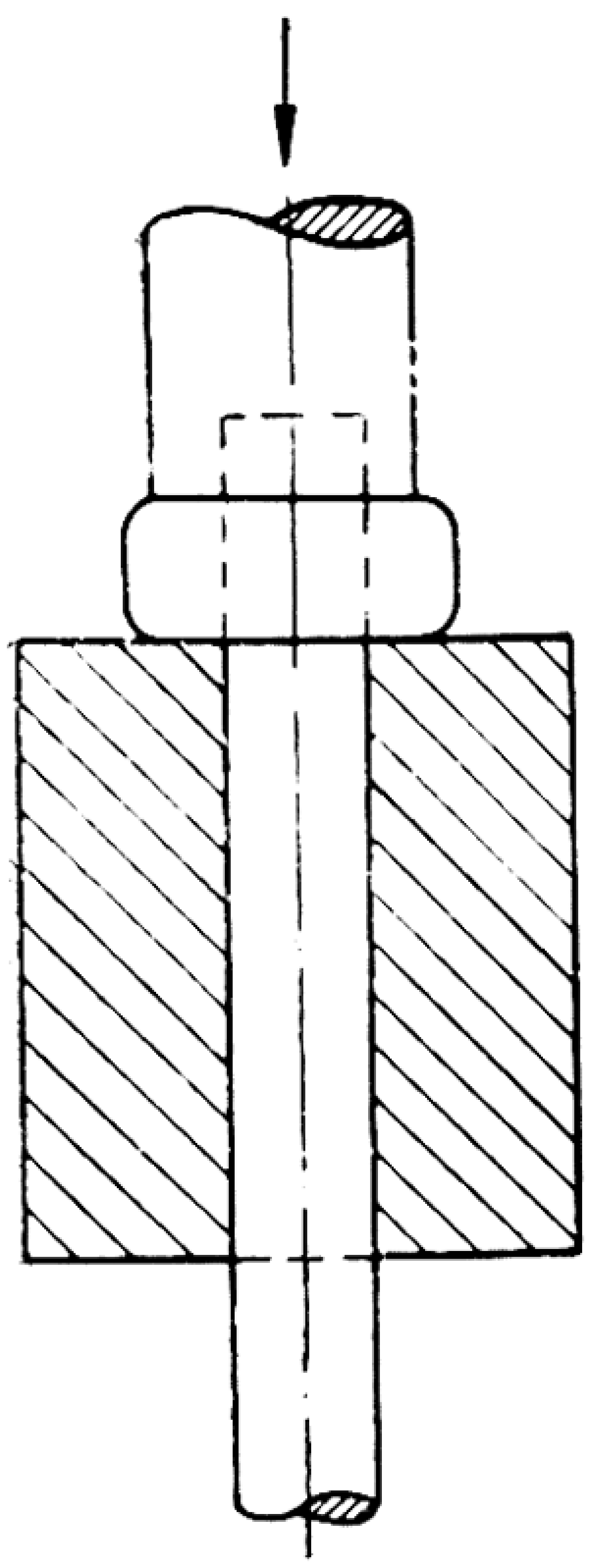


Fig. 282. Upsetting in open die

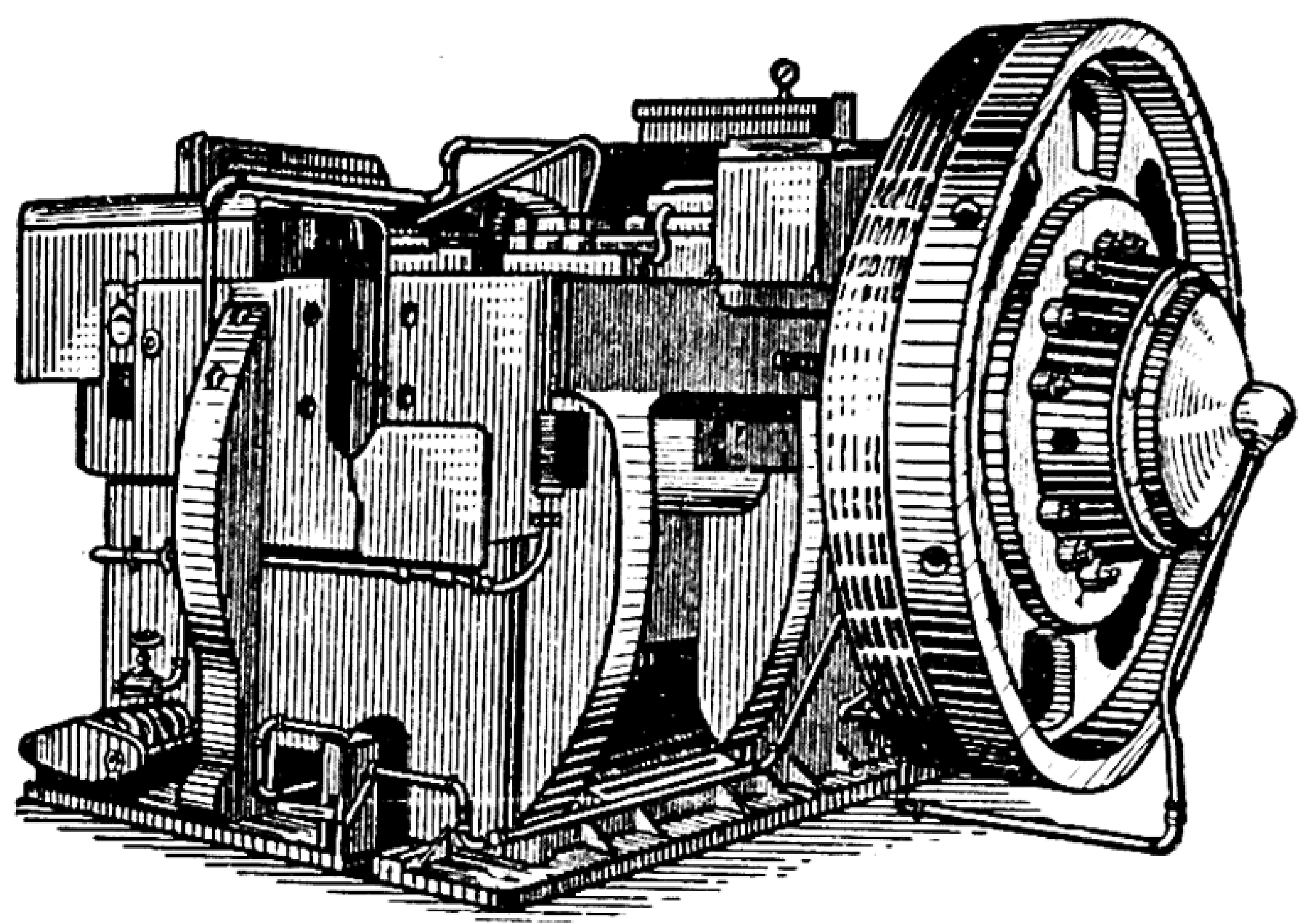


Fig. 283. Horizontal forging machine

results in rough edges on the work. Though horizontal forging machines are designed mainly for upsetting operations, they can also be used for a wide range of other operations, such as, punching through end dead holes (for instance, in flanges), bending, piercing holes, cutting, squeezing, trimming flash.

Principles of the Operation of Horizontal Forging Machines. Forging machines are classified into horizontal and vertical types, the former being the most widely employed (Fig. 283). Horizontal forging machines are designed for upsetting bars from 20 to 225 mm in diameter and with a maximum metal deforming pressure ranging from 50 to 3,000 tons.

Fig. 284 shows the gearing diagram of a horizontal forging machine. Here, electric motor *1* rotates flywheel *2* which is mounted on drive shaft *4*; this shaft, through a system of gears, rotates crankshaft *5*, connected to sliding block *6* through connecting rod *16*. Sliding block *6* carries heading die slide *13* in which heading die *12* is inserted. Connecting rod *16* connects the sliding block only when the foot treadle is depressed. The free end of the connecting rod then enters the recess of the sliding block, thereby actuating the latter. Through levers *17* and with the aid of eccentrics *7*, lateral sliding block *8* will actuate gripping die slide *9*, which carries gripping die *11*. The second, stationary, die *10* is secured in stationary die-holder

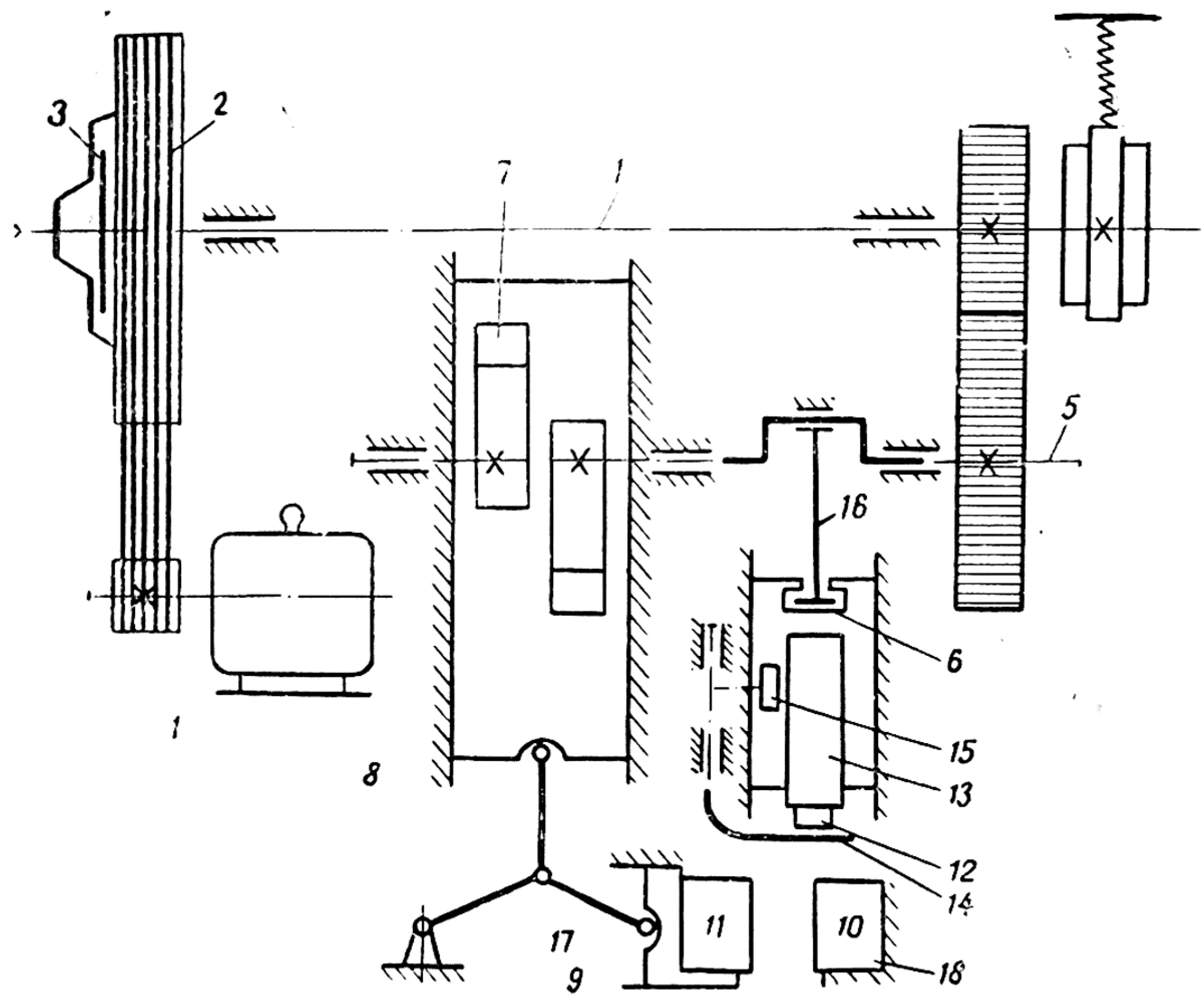


Fig. 284. Gearing diagram of horizontal forging machine

18. The movements of sliding block *6* and gripping die slide *9* are adjusted so that the stock to be upset, when inserted in the machine up to stock-gauge *14*, is gripped between gripping die slide *9* and stationary die-holder *18* and only after this does heading tool *12*, secured in heading die slide *13*, commence to move. Stock-gauge *14* is now withdrawn from the range of travel of the slide by roll *15*. During its return stroke, the heading tool recedes from the dies, and

the die-holders release the work. The dies must be very precisely installed, as, if their grip on the stock is weak, the heading tool will force the work out of them.

The *following rules* must be observed when operating horizontal forging machines:

1. Before commencing operations, make sure that all parts of the machine are in proper condition; see that the dies and the heading tool are properly secured and in good condition. Start the machine on idle load and commence operations only after making sure that all the mechanisms are functioning properly.
2. Before commencing work, always make sure that the diameter of the die impression corresponds to that of the stock. If the diameter of the impression is larger than that of the stock, the heading tool will force the latter out of the dies.
3. Before feeding stock into the dies, clean its heated end from scale.
4. See that the stock is fed perfectly straight into the dies and that it touches the stock-gauge.
5. Take particular care to see that, when feeding the last length of stock into the dies to make the final forging, the tongs or the chuck are kept clear of the dies.
6. During the operation of the machine never place your hand between the dies.
7. During the operation of the machine, always wear safety goggles to protect your eyes against scale.
8. Never forge metal the temperature of which has fallen below 850° C.
9. If the forging machine is not equipped with an automatic lubricating system, it must be lubricated only by a specially instructed greaser.

Examples of Work Done in Horizontal Forging Machines. As has already been said, horizontal forging machines can be used for a wide range of work—for upsetting heads of various shape and thickness on rods and bar stock; for bending and punching operations; for upsetting flanges on bar and rod stock, pipes, etc. Fig. 285 illustrates only a few examples of the work that can be done on horizontal forging machines.

We give below a few examples of drop-forging processes carried out on horizontal forging machines. Fig. 286 shows the technological process of *forging a nut on a 2" horizontal forging machine* from 22 mm diameter bar stock; each nut requires 137 mm of bar, 17 nuts being forged from one piece of stock.

The nuts are forged in four passes: the 1st pass—upsetting rod to length of 112 mm (Fig. 286, *b*); the 2nd pass—upsetting the bar to length of 76 mm (Fig. 286, *c*); the 3rd pass—forming nut (Fig. 286, *d*); the 4th pass—punching hole and trimming flash (Fig. 286, *e*).

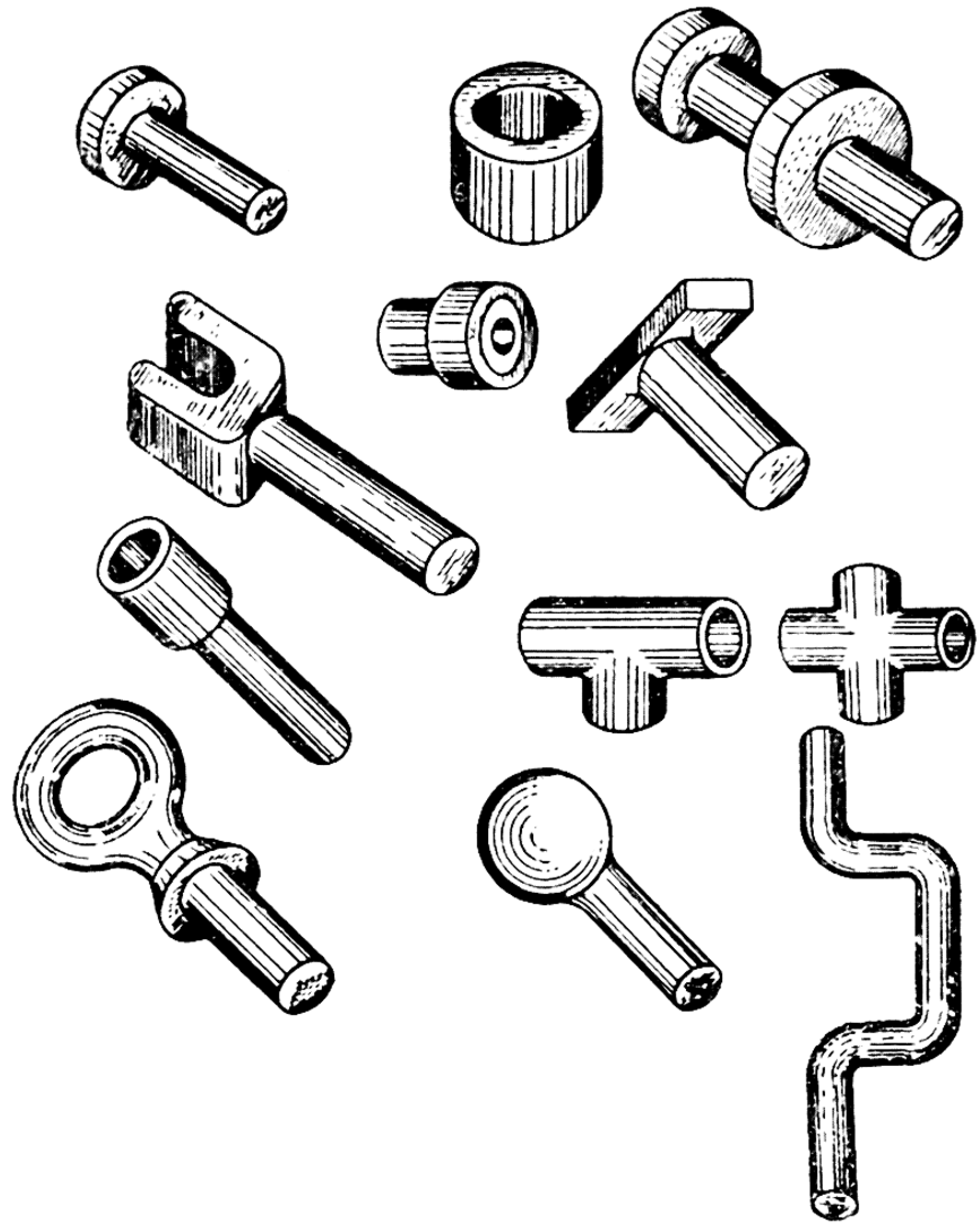


Fig. 285. Examples of forgings produced by horizontal forging machines

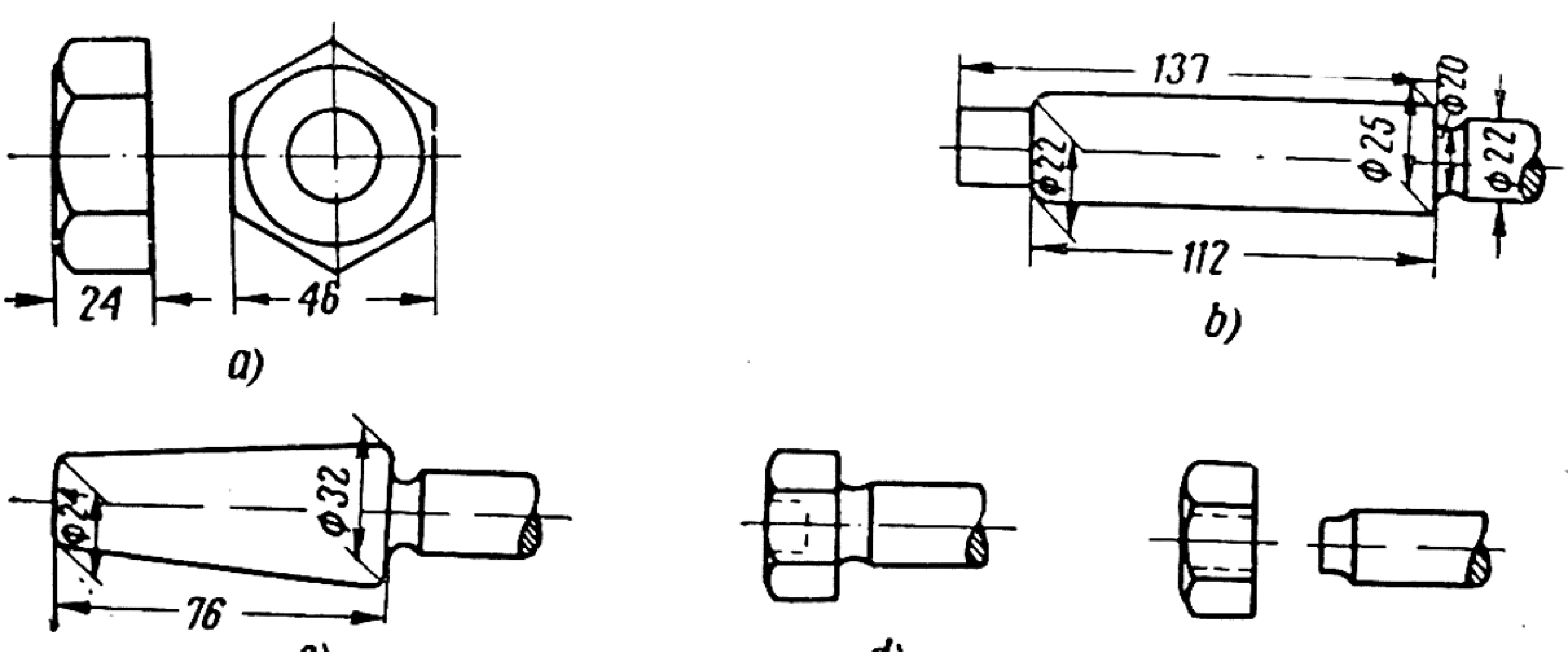


Fig. 286. Technological process of drop-forging nuts:
a) forging drawing; b, c, d and e) sketches of passes when making nut

Fig. 287 illustrates the technological process of *drop-forging a pinion shaft* on a 4″ horizontal forging machine.

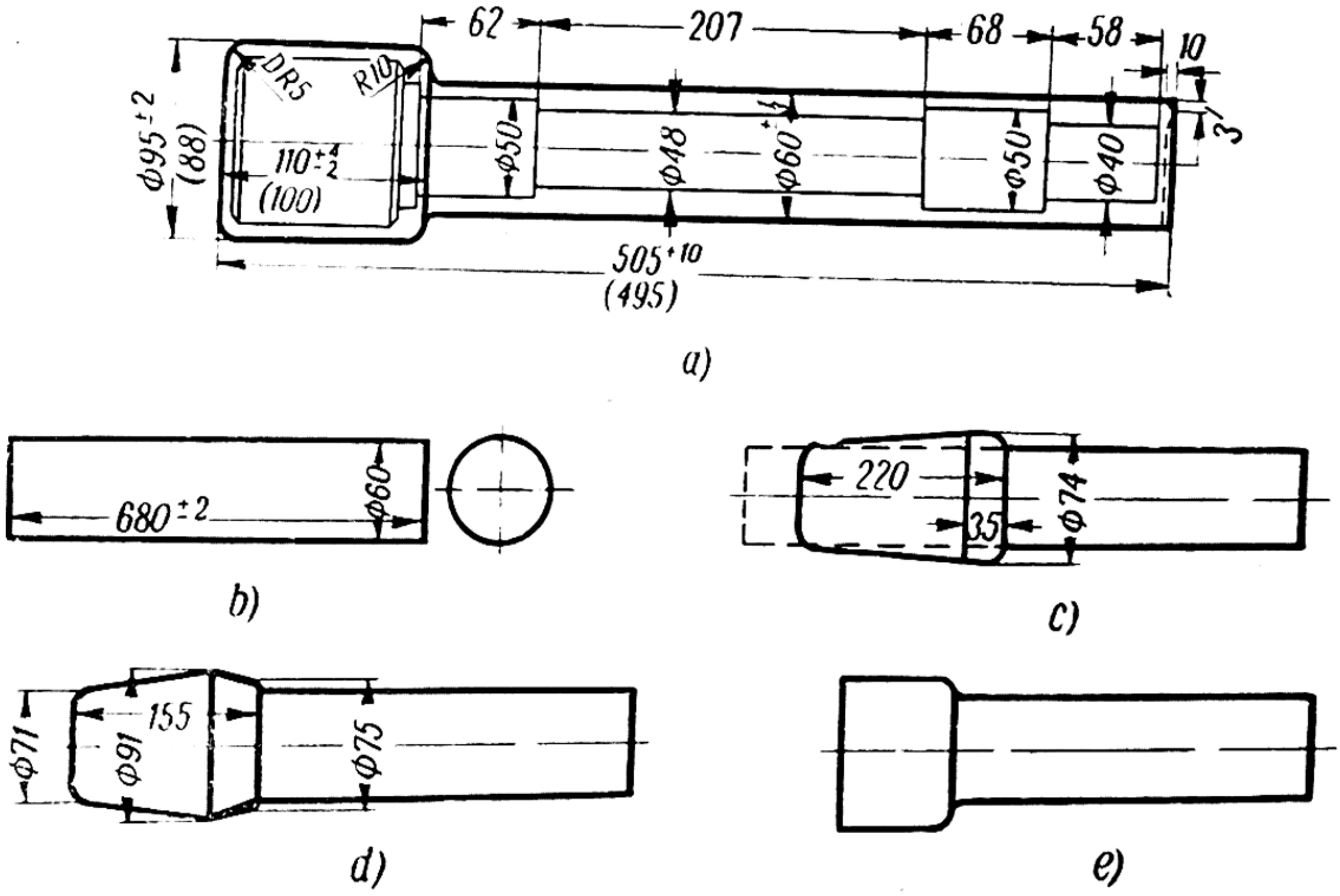


Fig. 287. Technological process of drop-forging geared shaft:
a) forging drawing of geared shaft; b, c, d, and e) sketches of passes when making geared shaft

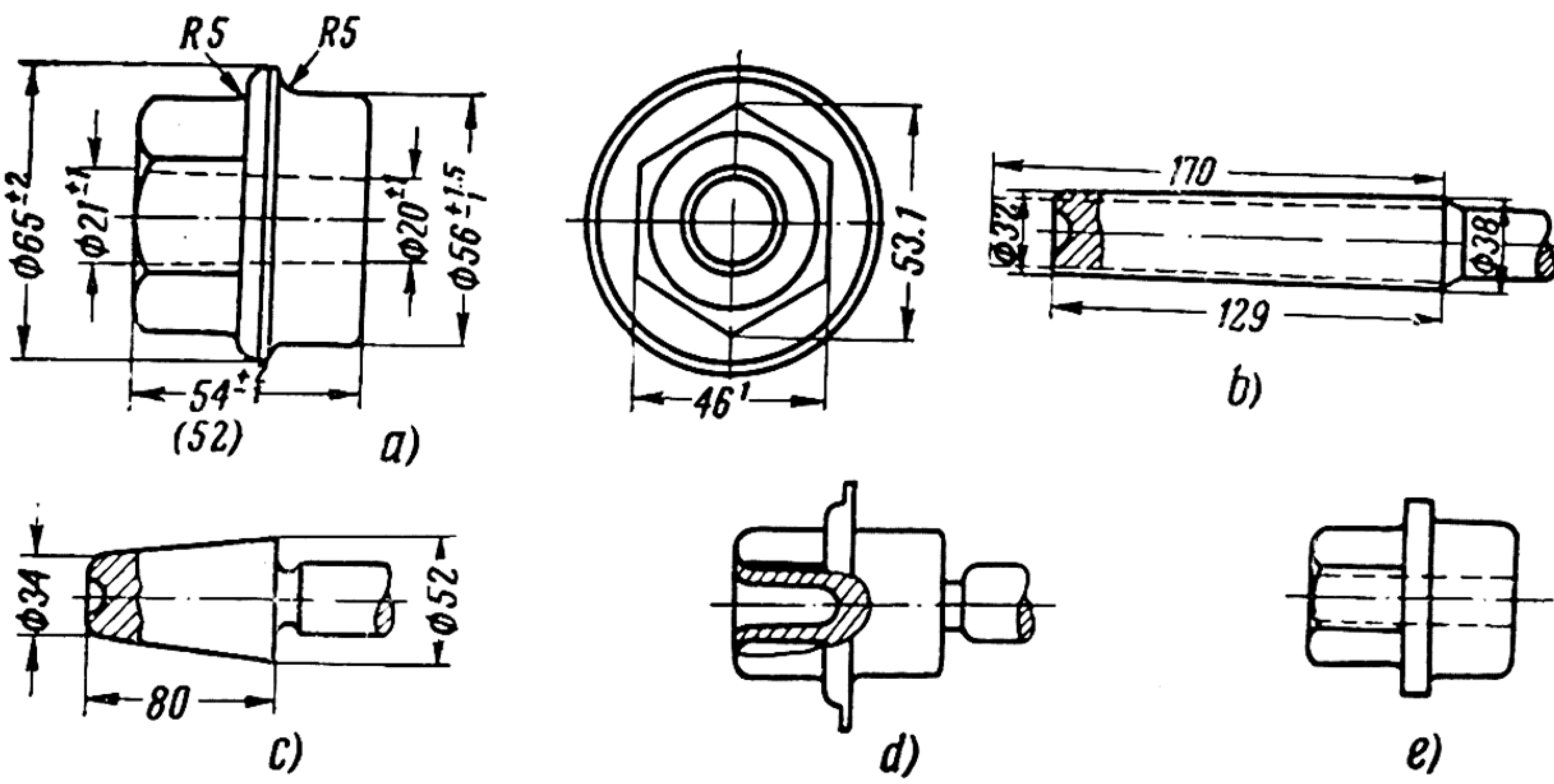


Fig. 288. Technological process of forging nut M 30×3.5:
a) forging drawing of nut; b, c, d and e) forging passes

The weight of the stock is 15.1 kg; that of the forging—15 kg. Material—steel, grade Ст. 40. The forging drawing is shown in Fig. 287, *a*. The pinion is forged in three passes; the technological chart calls for the following operations:

1) Inspection, checking dimensions and acceptance of stock against certificate;

2) Cold cutting stock to length (Fig. 287, *b*);

3) Upsetting in three passes: the 1st pass is shown in Fig. 287, *c*; the 2nd pass—in Fig. 287, *d*; and the 3rd pass—in Fig. 287, *e*;

4) Marking;

5) Acceptance after examination and checking dimensions.

The following tools are required for the above-mentioned operations: folding rule, shears, upsetting dies, marking stamp, hammer. The forging temperature interval for the 3rd operation will be 1,200-900°C.

Fig. 288 illustrates the technological process of *forging a M30 × 3.5 mm cap nut* on a 4″ forging machine. The forging sketch is shown in Fig. 288, *b*, *c*, *d* and *e*.

CHAPTER XIV

SPECIAL FEATURES OF FORGING NON-FERROUS METALS, TOOL AND ALLOY STEELS

SPECIAL FEATURES OF FORGING CARBON TOOL STEELS

Steels with a carbon content ranging from 0.6 to 1.4 per cent are called carbon tool steels. Such steels are distinguished for their hardness. The greater their carbon content, the harder they are, but the lower is their ductility.

Carbon tool steels are used for making all kinds of tools. In the forging industry they are used for forging and bench-work tools and also for dies. For instance, cold chisels, sledge-hammer heads, fitter's and blacksmith's hammer heads are made of grades У7 and У8 steel; punches, swages and smoothers—of grade У7 and grade У8 steel.

When forging carbon tool steels, it is always necessary to bear in mind their characteristics.

The plasticity of carbon tool steels is comparatively low and, as a result, they are not very malleable. Their plasticity falls considerably with their temperature. For this reason, the final forging temperature of carbon tool steels must be higher than the final forging temperature of engineering tool steels. Otherwise the steels will crack.

Carbon tool steels must be heated to a lower temperature than engineering tool steels for forging; and it should be remembered that the greater the carbon content in the steel, the lower the forging temperature must be; otherwise there is a danger of overheating and burning. Thus for carbon tool steels the forging temperature interval, i. e., the difference between the temperatures at the beginning and end of forging, will be narrower than that for engineering carbon steels. For this reason these steels require repeated heating when forging.

Table 11 gives the forging temperatures for carbon tool steels.

The thermal conductivity of carbon tool steels is lower than that of engineering carbon steels. For this reason carbon tool steels should be heated at a slower rate, and very cautiously. Carbon tool steel forgings should be cooled as follows: after the completion of forging, the work should be held in still air for 5 to 10 minutes (depending on the dimensions of the forging), until the temperature of its surface falls to about 700° C. Then it should be placed in dry sand or

Table 11

Forging Temperatures for Carbon Tool Steels

Grade of steel	Initial forging temperature, °C	Final forging temperature, °C
У7 and У7А	1130-1150	800-840
У9-У13 and У9А-У13А	1100-1120	820-870

slag and kept there until it completely cools. Carbon tool steel forgings must be cooled in sand or slag to prevent the development of cracks.

Before proceeding to forge the stock, it must be carefully examined for cracks, blebs and other surface defects. Shallow surface defects must be chipped out before forging. In addition it is necessary to make sure that the stock is made of the required grade of steel.

When producing carbon tool forgings on a mass scale, the quality of the steel should be checked by taking a fracture test once or twice during each shift. For this purpose, a test bar 10×10 mm in section is forged, notched, hardened and broken. The fracture should be a dull gray (matt).

The following defects may be met with when forging carbon tool steels:

Transverse cracks. This defect may be due to:

a) Rapid heating of the stock for forging, especially up to 800-900° C, when the surface of the stock reaches the furnace temperature while its core is still cold; the surface of the steel will expand to a greater extent than the core, resulting in considerable internal stresses at the core, and, consequently, cracks;

b) Incomplete heating of the stock throughout its cross-section, as a result of which the metal in the core will be less ductile than at the surface; such a piece of stock will crack on being forged.

Surface cracks. Cracks develop on the surface of a piece of stock when the metal cools rapidly during the process of forging; to prevent the formation of surface cracks, it is necessary to:

a) Forge the work with rapid, energetic blows, turning it after every 2-3 blows;

b) Conduct the forging so as to avoid the formation of sharp corners and edges which cool rapidly and lead to cracks. All sharp corners should be rounded off immediately they are made.

All cracks must be chiselled out during forging immediately they occur. If the surface of the forging becomes cold (darkens), forging should be ceased immediately and the stock reheated.

Spalling. The stock splits into several pieces under the blows of the hammer if the metal is burnt.

SPECIAL FEATURES OF FORGING ALLOY STEELS

As is known, steels containing special useful alloying elements in addition to carbon are called alloy steels. Each of these alloying elements affects the properties of the steel to a greater or lesser extent. These alloying elements are: chromium, nickel, molybdenum, tungsten, aluminium, cobalt, and also silicon and manganese if they are added in quantities which exceed their normal content in ordinary steels.

The thermal conductivity of a steel is of decisive importance in selecting its heating conditions. As a rule, the thermal conductivity of alloy steels is lower than that of carbon steels. Alloy steels are not so plastic as carbon steels, and are also more liable to form cracks. Moreover, they are more susceptible to overheating and burning than are carbon steels.

The plasticity of a steel increases with its temperature. For this reason, alloy steels may be heated at increased rates at high temperatures without fear of cracking. At low temperatures, however, when the plasticity and the thermal conductivity of the steels are low, they must be heated at a slower rate and with more caution.

From the foregoing the following *conclusions* can be drawn as regards the special features of heating alloy steels.

1. Ingots should be charged into furnaces at as low a temperature as possible. There are several methods of heating ingots of alloy steels: a) charging the steel into a cold furnace and heating it together with the furnace; b) heating the ingot first in a furnace at a low temperature and then transferring it to a second furnace at a higher temperature; c) heating the ingot in a double-chamber furnace, in which one chamber, heated to a lower temperature than the second, serves as a preheating chamber; d) heating the ingot in a continuous furnace, in which the steel is gradually heated as it travels from the charging to the discharging end of the furnace.

2. The heating cycle for alloy steel ingots must consist of three periods: a) a period of slow heating in the low plasticity and low thermal conductivity range of the steel, i. e., up to 550-600°C and for certain very brittle steels, up to 700-800°C; b) a second period, of more rapid heating, up to the forging temperature; c) a third period, during which the metal is held at a constant temperature in order to bring the ingot to a uniform temperature throughout its cross-section.

3. Rolled alloy steel stock with a cross-section of approximately 100×100 mm can be rapidly heated in the same way as ordinary carbon steel.

4. The total duration of heating alloy steels is longer than that of heating simple carbon steels.

5. The duration of heating alloy steels varies with their grade. Table 12 gives the heating conditions for forging certain grades of alloy steels.

Table 12

Forging Temperatures of Alloy Steels

Grade	Maximum temperature of metal, °C	Maximum temperature of furnace, °C	Final forging temperature, °C	
			for preliminary operations	for final operations
15X; 20X; 35X; 40X; 30H; 40H; 2XCMA; 34XM	1220	1270	800	700
18XHMA; 5XHM; 75XГM; 6XHM; 45XH	1200	1250	800	700
X3; 9X; 9X2	1150	1200	850	800

Before proceeding to forge alloy steel, all cracks, laps, etc., and in general all defects resulting from the pouring of the steel in the moulds or the rolling process must be removed from the surface of the stock or ingot.

This is done either with a pneumatic chisel or with an emery grinding wheel. Sometimes the entire surface of alloy steel ingots is rough machined on special machine tools. After the defects have been removed, the ingot is charged into the furnace and heated for hammer or press forging. The temperature of the furnace, as well as the initial and final forging temperatures, must be carefully controlled.

Each grade of alloy steel has its own forging temperature interval, which must be always adhered to.

The ingot should be reduced gradually, beginning with slight (20-30 mm) reductions; it is only after the first and, preferably, after the second reduction, that the amount of reduction may be increased. This method will prevent surface cracking. If, however, surface cracks do appear during the forging of the ingot, they must be immediately chipped out. After chipping, the ingot must be reheated and forging continued.

The following *rules* must be observed to ensure high-quality alloy steel forgings:

1) Work on hammers or presses of high capacities;

2) Always upset the work two or three times, depending on the nature of the forging;

3) After each upsetting and subsequent drawing (reducing), anneal the forging;

4) As the forging temperature interval for alloy and carbon tool steels is comparatively narrow, the dies, inserted tools, such as rings, plates, etc., should be heated to 400-500° C before beginning to forge such steels, in order to minimise the cooling effect of the cold dies on the steel;

5) The working surfaces of the tools (dies, plates, etc.) must always be maintained in good condition and kept free from dents, scratches, etc.

FORGING NON-FERROUS METALS AND THEIR ALLOYS

Hot and cold stamping of non-ferrous metals and their alloys is widely practised in industry, particularly in the aviation and engine-building industries. Non-ferrous metals and their alloys are seldom forged by the hammer forging process.

Non-ferrous metals and their alloys are forged in machines of the same types as those used for forging ferrous metals, and with similar tools. The forging and stamping of non-ferrous metals and their alloys are based on the same principles as those used for ferrous metals. However, mention must be made of certain specific features which must be taken into consideration when forging and stamping non-ferrous metals and their alloys.

Non-ferrous metals and their alloys intended for forging can be classified into two groups: heavy and light metals and alloys. The first group includes copper, bronze, nickel, nichrome and brass.

The second group covers light metals and their alloys—aluminium, duralumin, and magnesium alloys. The chief conditions for forging some of these alloys are as follows.

Copper is used mainly in the electrical industry for manufacturing parts of electrical apparatus, busbars, wires, etc. Copper is not very ductile at temperatures from 250 to 600° C, and cannot be forged or stamped at temperatures above 800° C, due to its high brittleness. Pure copper is very seldom forged or stamped, and usually only its alloys—bronze and brass—are subjected to forging and pressing.

Brass is an alloy of copper and zinc. So-called malleable brass, consisting of 59 per cent of copper, 45 per cent zinc and from 1 to 0.5 per cent lead, is most frequently subjected to forging and stamping. Sometimes brass containing no lead is used for stampings. Brass is stamped on the same kind of equipment and by the same methods as those employed for stamping steel. Brass can be heated in ordinary forge furnaces which ensure a uniform temperature.

When stamping brass, its following characteristics should be borne in mind. In the first place, the forging temperature range of brass is very narrow—from 730 to 750° C, and its optimal forging temperature interval ranges from 730-720°C. Therefore brass must be stamped very rapidly, preferably at one blow. Secondly, trimming must be effected at the forging temperature interval, i. e., between 730 and 720° C, or after the forging has cooled to room temperature.

Bronze is an alloy of copper and aluminium, tin and other elements. Aluminium bronze is very easily forged and stamped in presses and hammers. Its forging temperature interval ranges from 900 to 750°C. Bronze can be heated in the furnaces employed for heating steels.

Aluminium and *duralumin* are metals silver in colour, highly plastic and easily stamped.

Duralumin is an alloy of aluminium and copper (up to 4.5 per cent), manganese and magnesium (about 0.5 per cent each). Forging temperature intervals for aluminium: 475-425° C; and for duralumin: 470-380°C.

Aluminium alloys are particularly widely employed in the aviation industry, because of their light weight and high strength. Aluminium and its alloys are usually heated in electric furnaces, the rate of heating being far slower than that of steel.

When forging and stamping aluminium and its alloys, which can be carried out on both hammers and presses, the following features must be borne in mind:

1) All the forging tools (stamps, dies, etc.) must be heated to 200-250° C before commencing operations;

2) Experience shows that rectangular ingots and stock can be forged more easily than round ones, which frequently display cracks on forging. For this reason, round ingots and stock should not be used;

3) Aluminium alloys have a tendency to stick to the surface of the dies, thereby resulting in forgings with rough surfaces. For this reason the surfaces of the dies and their impressions must be very carefully polished. During stamping and forging these surfaces must be lubricated, and the dies heated to 200-250° C before starting work. They may be lubricated with a mixture of graphite and vegetable oil or masout;

4) Mixtures of aluminium powder and iron scale are highly explosive, yet both aluminium and steel forgings are frequently produced in the same forge shop. Precautions should therefore be taken in order to exclude all possibility of mixing aluminium dust and iron scale and, thus, the possibility of explosions.

CHAPTER XV

HEAT TREATMENT, DEFECTS AND INSPECTION OF FORGINGS

COOLING FORGINGS

Steel forgings are heat treated for the following purposes: 1) to remove stresses arising in the steel during forging and cooling; 2) to equalise the structure of the metal of the forging; 3) to give the steel that degree of hardness which makes it most easy to machine; and 4) to improve the mechanical properties of the steel.

As has already been said, the forging of steel is completed at a fairly high temperature (800-900°C). When forgings cool, deformations (stresses) arise in the steel; and in the process of forging the magnitude of these stresses may exceed the strength of the steel itself. As a result, what are called *micro-cracks* may occur in the steel; these are cracks which cannot be seen with the naked eye, though sometimes very large cracks also occur. This leads to the rejection of the forging.

On cooling, the difference in temperature between the surface and the core of the forging causes internal stresses to arise. As is known, a forging begins to cool on the surface. Therefore the temperature at its surface will always be lower than at its core, and the temperature of the metal will increase towards the centre of the forging. The surface of a forging cools and contracts considerably more rapidly than the hotter, central, layers. As a result, the surface layers will strike to compress the internal layers of the forging, and the internal layers will tend to distend the surface layers.

As the layers of metal continue to grow cooler (i. e., when the surface layers of the forging are almost cold), the contraction of the surface layers practically ceases; but, as the outside layers of the metal are cold, the metal itself loses a considerable amount of its plasticity. At the same time, the temperature of the inner layers of the metal of the forging will still be high, and these layers will continue to contract. As a result, the direction of the stresses changes:

compressive stresses are now present in the outer layers, and tensile stresses in the inner layers.

As has already been mentioned, cracks occur in the forging when the stresses due to the cooling of the steel exceed its tensile strength. The occurrence of cooling cracks depends on the quality of the steel. Heterogeneity of the steel, the presence of bubbles, pipe cavities, non-metallic inclusions, etc., facilitate the development both of internal and surface cracks. Thus the conclusion can be drawn that forgings must be cooled in such a way as to promote the complete or partial absence of stresses in the steel as it cools.

If a forging is cooled slowly from 800-900°C, its temperature throughout its entire cross-section will gradually become equalised. This will result in the disappearance of all residual deforming stresses set up in the steel during its forging; the stresses arising in the steel resulting from the difference between the temperatures of the surface and internal layers of the forging as it cools will be reduced.

A forging can be cooled by one of the following methods: 1) cooling in air; 2) cooling in unheated pits; 3) cooling in heated pits or in the furnace. The cooling method selected depends on the grade of the steel and the shape and cross-sectional area of the forging. The method of cooling, and the cooling rate, must be indicated in the process chart for a given forging.

The quickest cooling method is that of cooling *in air*. For *air cooling*, forgings can be packed in three different ways: 1) in a single row, without clearances; 2) in a single row, with clearances, and 3) in stacks. The highest cooling rate is attained by placing the forgings in a single row, with clearances between each forging; they will cool rather more slowly when placed in one row without any clearances between them; while the rate of cooling will be slowest when they are stacked one on top of another. When cooling forgings in air, they must always be placed on dry soil. If placed on damp soil, or on a metal floor, or on cold forgings the cooling will not be uniform. The locality for air cooling must be protected from draughts.

Cooling in pits (or wells) is a slower process than air cooling. The rate of cooling in pits or wells can be controlled by opening and closing the pit covers, by covering the forgings with poor heat-conducting materials, such as dry sand, slag wool, coal ashes, etc., of varying thickness. Forgings should never be charged into cooling pits at temperatures below 500-550° C. They should be stacked in the cooling pits not touching the cold walls. If the forgings in the pits are to be covered with sand, slag wool, etc., care should be taken to leave a clearance of 25-50 mm between each forging; this clearance must also be packed with a dry, poor heat-conducting material. The

forgings must then be covered with an 80-100 mm layer of the same material.

Cooling in hot furnaces is employed for more important forgings, whose cooling must be carefully controlled in accordance with a definite predetermined rate. Before charging the forgings into the furnace, the latter must be heated to 500-700° C, but never less than 500-600° C. Forgings are generally cooled in car-bottom hearth furnaces.

If the forging is to be heat-treated, for instance, annealed, the cooling process should be combined with the annealing process. For this purpose, the forgings are charged into the furnace at temperatures not below 500° C, and then heated to the required annealing temperature, after which they are cooled in the furnace according to specified conditions. This method will reduce the cooling time and the fuel consumption, since it eliminates one heat and one cooling.

ANNEALING AND NORMALISING FORGINGS

Annealing is a form of heat-treatment which is applied to remove stresses, and improve the mechanical properties and machineability of forgings.

The annealing process consists in heating the forgings in a furnace to a temperature of 750-900° C, depending on the carbon content of the steel (to a temperature 20-50° C above the A_{c3} point), with subsequent slow cooling. This annealing will result in: 1) refinement of the grain formed in the steel on the completion of forging at high temperatures; 2) removal of internal stresses resulting from the hot working of the metal; 3) comparative softening of the steel, thereby improving its machineability.

Normalising forgings consists in heating them in furnaces as in annealing, and then removing them from the furnace for subsequent cooling in the air. The following results are achieved by normalising: 1) a fine-grained structure, the grain being refined to a greater degree than by annealing; 2) improved mechanical properties—increased tensile strength and ductility; 3) removal of internal stresses.

DEFECTS IN HAMMER FORGING

Forging defects may result from the following causes: 1) poor quality of the stock; 2) improper heating; 3) incorrect forging conditions; 4) wrong forging methods; 5) uneven cooling of stock after forging.

The quality of the finished forging always depends on the quality of the stock; a good forging cannot be made from a piece of stock

of poor quality. Before starting to forge a piece of metal, it is necessary to ascertain its quality, and for this reason it is first subjected to chemical analysis and mechanical tests. If the results of the test and analysis do not meet the required specifications for the given work, the steel must be rejected or used for some other part for which it is suitable.

Good quality steel which meets all the specifications for a given piece of work may be spoiled as a result of uneven heating, incorrect forging conditions such as, for instance, excessively high or low final forging temperatures, or by the use of wrong forging methods.

If a forging is not cooled uniformly, internal stresses will occur in the metal, resulting in distortion of the forging or in cracks. An excessively oxidising furnace atmosphere will result in the decarburisation of the surface of the steel, and the lowering of its mechanical properties; this fault is difficult to remedy. If this occurs such alloy steel forgings should be used for parts not exposed to severe duty conditions. The chief defects mentioned above may be divided into *two groups*: a) irremovable defects and b) defects whose harmful influence can be partially or completely removed. Irremovable defects include: deep cracks, tears, cavities, burnt metal, and decarburisation. Removable defects include: shallow cracks, overheating, coarse-grained structure, internal stresses and distortion.

Defects in hammer forgings or stampings can be remedied as follows:

1. Shallow cracks and cavities can be removed by chipping out of the cold forging with pneumatic chisels or with hot sets during the forging process.
2. Surface cracks and decarburised areas are removed from important forgings by grinding on special machines.
3. Distorted forgings are straightened in presses.
4. The mechanical properties of the steel can be improved and internal stresses removed by annealing or normalising.

The chief defects which are met with in forgings are the following.

Cracks. Longitudinal and transverse cracks are the most common forging defects. Their occurrence may be due to: a) bad quality of the ingot; b) improper heating; c) forging at low temperatures; d) incorrect cooling of alloy steel forgings; e) employment of incorrect forging methods.

Cracks which occur during forging must be removed with hot sets while the forging is still hot; this is cheaper than chiselling the cracks out of a cold forging. Cracks are cut out of hot forgings as follows. The hot set is put on the forging and forced into the metal slightly

above the place where the crack has been discovered; then the forging is turned round slightly and the crack cut out by striking the hot set lightly with the hand or sledge-hammer.

Hair Cracks. These are very fine cracks not exceeding a fraction of a millimetre in width. They can occur due to: a) defects in the metal (ingot); b) too rapid cooling of the forging.

Slags, Sand and Porosity. Slags, sand and porosity, occurring either on the surface of, or inside the forging, may be due to defects in the ingot or to incomplete discard of the ingot head.

Honeycombs and Cavities. Honeycombs and cavities may occur when forging round work under flat dies if the work was drawn out to a round section without being previously forged down to a square section.

Tears. Tears are the result of: a) forging at low temperatures during the cogging of the ingot; b) bad quality of the ingot; c) burning as a result of incorrect heating.

Pitting. Pitting is due to the incomplete cleaning of dies from scale, which is then forced into the surface of the work during its forging.

Laps. Laps are due either to careless work on the part of the blacksmith (excessive gripping of the work by the dies) or to forging with dies which are not in proper condition (edges not rounded off).

DEFECTS IN FORGINGS DURING HOT STAMPING

Various defects may occur in the work during hot stamping.

Dimensions of Forgings Do Not Correspond to Those Specified in the Drawing. It should never be supposed that forgings made with the same set of dies will always be exact copies of each other and that their dimensions will be strictly in accordance with those specified in the drawing. Actually, this is not so. Dies work under very severe conditions (high temperature resulting from their contact with hot metal, and heavy blows); in the process of their work, they constantly get out of adjustment and rapidly wear out, thereby losing their original dimensions.

If a forging gets stuck in the finish impression of a die, this is an indication that the die is worn out. Worn dies result in forgings of greatly increased dimensions, with machining allowances of double and even triple the specified values. In order to check the condition and wear of a die, and also for checking dies after repairs, the work must be examined, measured and weighed systematically after making a definite number of forgings.

Die Shift. In the process of operation, dies very often get out of adjustment. The bottom die must always be installed so as to be per-

fectly rigid; it must be secured without linings; and the adjustment will then consist only in matching the top and bottom dies. After they have been properly matched and suitably adjusted, a trial forging is made.

After checking the forging, the inspector and foreman must report as to the fitness of the trial forging, and only after it has been pronounced as being in order and they have given their permission, can the smith proceed to forge the entire lot. But, however perfectly the dies may be installed and secured, they will get out of adjustment as a result of vibrations due to impacts during the process of work.

Forging with shifted, or mismatched, dies will always lead to misalignment of the forging (Fig. 289). This is easy to ascertain before the work has been trimmed and the flash cut off. If such a forging is looked at in the direction of the plane of the flash, it can easily be seen that one half of the forging is displaced (shifted) relative to the other. A forging with die shift visible to the eye must be rejected as spoilage. For this reason, the drop forge operator must always check his work from time to time for die shift, and tighten up the wedges before they get loose. Should any die shift be observed, work must be stopped and the dies readjusted.

Incomplete Filling of Dies. The dimensions of forgings which do not completely fill their dies (Fig. 290) will never correspond to those specified in the drawing; usually such forgings are rejected as spoilage. Incomplete filling of dies is the result either of an insufficient number of blows during forging or of forging the stock at too low a temperature, when it has partially

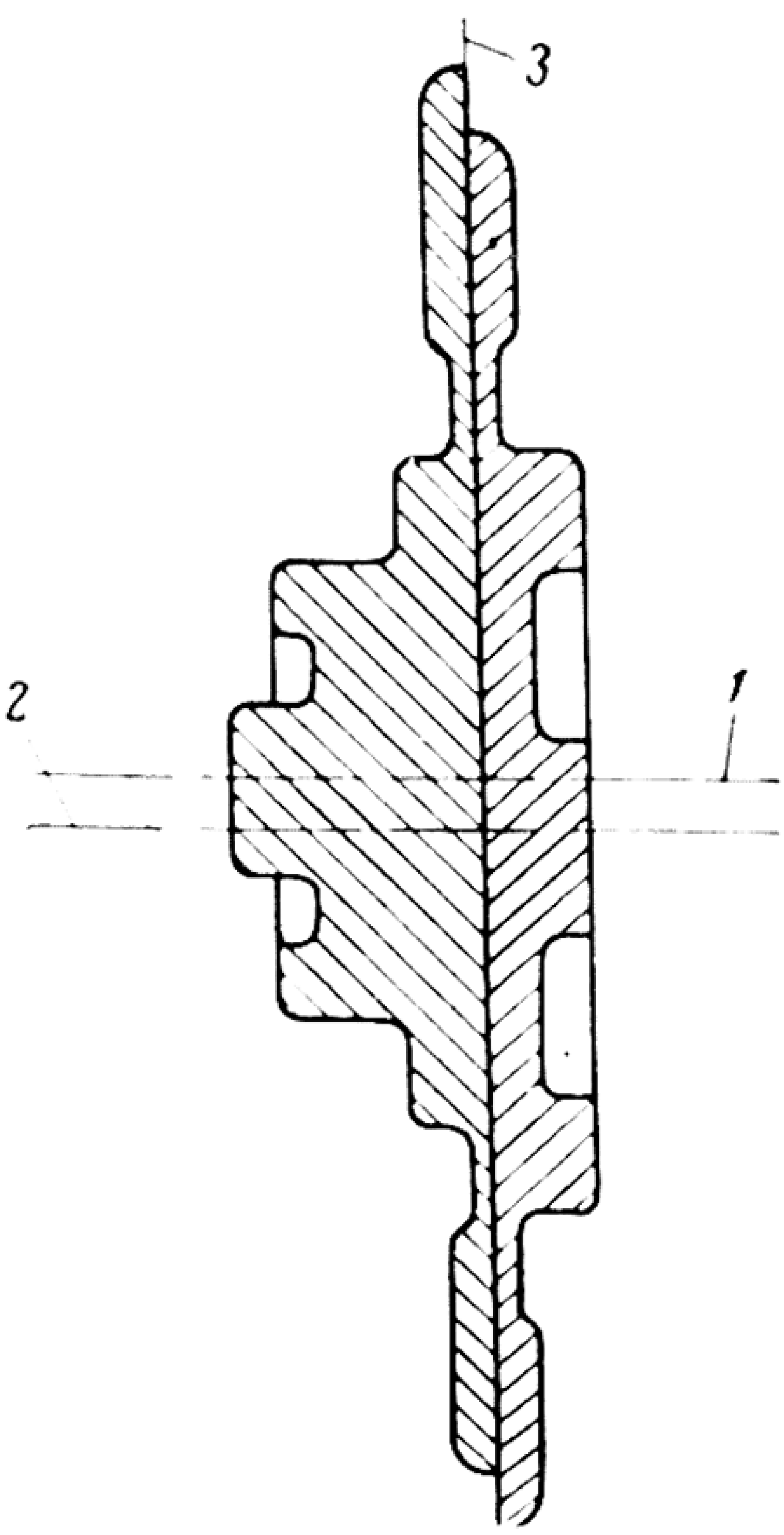


Fig. 289. Misalignment of a drop-forged gear blank:

1) axis of top half of gear blank; 2) axis of bottom half of gear blank; 3) die parting line

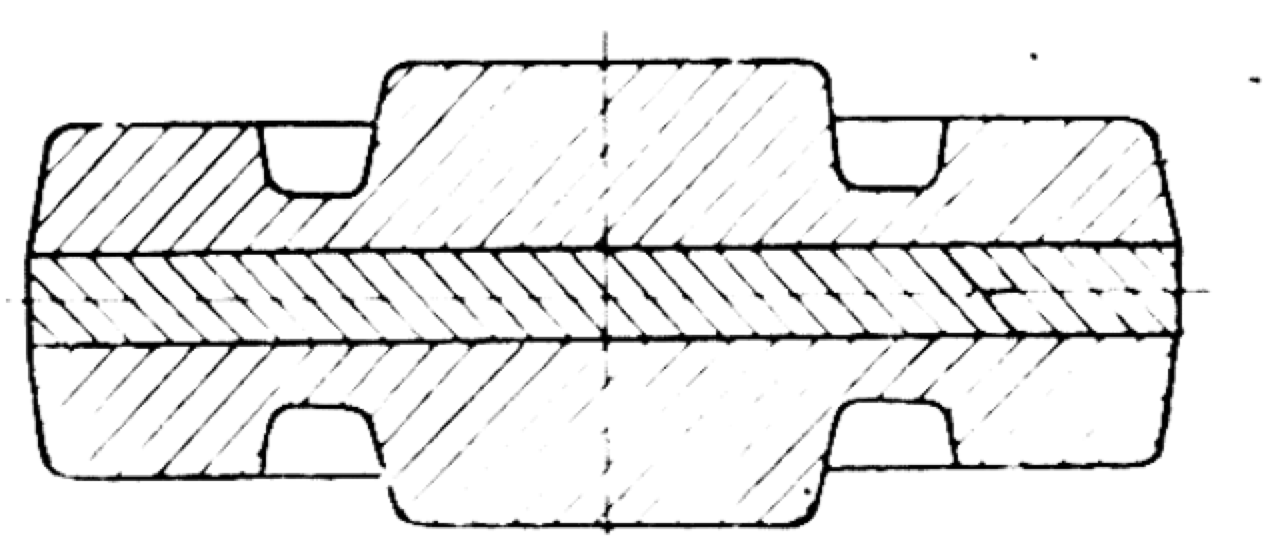


Fig. 290. Incomplete filling of die

lost its plasticity, thereby failing to fill the impressions of the dies.

Cold Shuts, or Laps. Cold shuts result from an improper flow of the metal, and consequent incorrect filling of the die. The occurrence of cold shuts on a large scale is due to incorrect die design, when the preliminary and rough impressions do not conform to the finishing impression; this, in turn, results in the improper flow of the metal, leading to the formation of cold shuts. They can also result from the improper insertion of the rough forging into the finishing impression of the dies. In this case, cold shuts will be accompanied by excess flash around the entire contour of the forging.

Pitted Surface. Pits are surface depressions formed on a forging by scale left on the dies during the forging operations if they are not properly cleaned. The scale accumulated in the impressions of the die is forced into the hot, plastic stock, thus forming deep cavities, or pits. Such pitted forgings must be rejected, as black spots will be left on the forging after machining. Pitting can be avoided by blowing over the forging and the impressions of the die with hot air before commencing forging.

Dents. Dents are the result of careless work: 1) when the stock is incorrectly inserted in the die, before making the final blow; 2) when the forging sticks in the top die and falls out of it at the moment of impact; 3) when hot forgings are thrown from place to place; and 4) when forgings are trimmed in badly adjusted trimming dies.

INSPECTION AND ACCEPTANCE OF FORGINGS

All finished forgings are inspected for quality. The aim of quality inspection is to ascertain whether the strength of the forging meets the conditions for which it is designed.

Inspection consists of the following *operations*:

1. Visual examination of the surface of the forging for complete filling of the dies, cracks, hair seams, tears, cold shuts, blebs, etc.

2. Checking the dimensions of the finished product. This is done by checking the dimensions of the forging with measuring instruments and comparing them with those specified in the drawing. The results of this check will determine if, after machining, the forging will yield a finished product meeting the customer's specifications.

3. Testing the mechanical and physical properties of the forging. This is done in laboratories on special test specimens. These specimens are cut from special sample allowances provided on the forging, which are left or cut out at those places where the part will be sub-

jected to the severest duty, or where the quality of the metal is known to be the lowest (for instance, when forging from ingots, the sample is taken from that part forged from the head discard of the ingot).

4. Hardness tests are performed on the surface of the work; for this purpose, the work is cleaned with an emery wheel at the spot where it is to be tested for hardness. These tests are made on special hardness testing machines, previously described. In addition to the above quality tests, test specimens of important forgings are subjected to macro- and micro-structural analysis, for which special micro-sections are made.

CHAPTER XVI

ORGANISATION OF WORK AND OF THE WORKING PLACE

RATIONAL UTILISATION OF FORGING EQUIPMENT

Whenever a new order for the production of forgings is received in a forging shop, the question arises and has to be decided, which is the best type of hammer, press or forging machine to employ for the manufacture of the given forgings.

A forging process chart is first drawn up; it specifies the method of production, and the equipment and tools with which the forging is to be made. But every blacksmith should understand the reason for selecting any given method and equipment for the production of a given forging. This is necessary so that he may be able to improve the technological process, increase his labour productivity, and to strive to lower the cost price of the forgings.

The choice of a forging method, and the selection of forging equipment will depend on the quantity of forgings to be made and on their cross-section. If the quantity is comparatively small, and it is not expected that the order will be repeated, then it will be most profitable to make them by the hammer, or smith forging, method in a steam hammer or in a forge press. If, on the other hand, the order calls for a considerable quantity of duplicate forgings, and it is expected that order will be repeated at a later date, it is more advisable to produce them by stamping in a drop-forging hammer, or press, or by upsetting in a forging machine.

The required capacity of the forging equipment depends on the cross-section of a forging. The correct choice of forging equipment is highly important. If the forging hammer or press is not sufficiently powerful, the production of the forging will take much time, entailing extra heatings and consumption of fuel and, consequently, increased expense. Moreover, the work produced in such hammers or presses will never be thoroughly forged throughout its entire cross-section, and such forgings will have low mechanical properties. On the other hand, forging units of too high a capacity should never be selected, as they will also increase the cost of the forging.

Increasing the Productivity of Forging Equipment. Every hammer press and forging machine manufacturing plant always indicates the productivity (or capacity) of its machines, i.e., the quantity of work,

in units of weight or in pieces, which the given equipment can produce per unit of time—for instance, per hour. Constant maintenance of equipment (hammers, presses, furnaces, etc.), and timely repairs, though this cannot completely do away with the need for capital repairs, will nevertheless reduce their frequency, and, therefore, reduce idle time.

The quality and dimensions of the stock likewise play a very important role in increasing productivity. The better the quality of the stock, the less the spoilage will be. Working with stock the dimensions of which are out of proportion to those of the finished forging will entail extra operations which might otherwise have been avoided. For instance, a piece of stock which is disproportionally thick will entail an extra drawing-out operation. Making forgings from long billets or blooms will entail cropping ends, which might be avoided by using a piece of stock of the proper length. The employment of various fixtures, devices and tools designed for lightening operations, and the drafting of rational technological processes, are also of paramount importance.

The forging of metals has from ancient times been considered as an arduous physical labour and, at the same time, as an art. And it is true that working with material heated to high temperatures and the necessity of giving this material a high degree of deformation in the exceedingly short period during which it retains its plasticity, demand a great effort of physical strength and high skill.

At present, the character and scope of modern forging production demands, with increasing persistence, the simplification and lightening of hand forging methods and, in particular, the transition from hammer forging production to die-forging. Wherever, for whatever reason, this transition is not yet advisable, it is necessary to lighten hammer forging by mechanising arduous hand operations—by the use of various devices and by executing at least some of the forging operations in dies of the simplest design.

Some of the principal measures by which progressive forging operators simplify and increase the speed of their work, are: 1) making convenient hand tools; 2) using fixtures and devices which lighten forging operations on heavy stock; 3) using fixtures which help to combine several hand forging operations into one; 4) using special tools for each operation (fullers, spreaders, sets, extensions, etc.) instead of universal hand forging tools; 5) using simple fixtures and devices which can be substituted for dies; 6) redesigning tools so as to make hand forging operations easier; 7) making dies for small batches of duplicate hand forgings; 8) using fixtures and devices for mechanising hand operations; 9) reducing auxiliary time by employing fixtures for the simultaneous production of several forgings.

Increasing the Productivity of Furnaces. In forging practice, considerable time is frequently lost in waiting for the metal to reach the required temperature. This results in a considerable reduction of the productivity of the forging hammer or press. Idle time can be partially or completely done away with by: 1) replacing existing furnaces by new furnaces of higher productivity, or by installing extra furnaces; 2) introducing measures for increasing the productivity of the existing furnaces.

Sometimes local conditions, economic and other considerations make it inadvisable to install an extra furnace or to remodel existing furnaces.

Measures for increasing furnace productivity include: 1)utilising the heat of the flue gases to heat the metal in the pre-heating chamber of the furnace, thereby speeding up the heating rate and increasing the efficiency of the furnace; 2) reducing the time required to bring the stock to forging temperature by locating it on the furnace hearth so as to ensure the best conditions for exposing its surface to the heat of the hot furnace gases, and 3) rational charging of the furnaces with stock.

The best furnace charging method is to charge a cold piece of stock into the furnace at the same time as an already heated piece of stock is being discharged from the furnace. This method is recommended for heating all stock, with the exception of heating stock for small forgings, when the forging or stamping process is very rapid, and the furnace operator cannot deliver heated stock to the hammer or press and, at the same time, charge new stock into the furnace; in such cases, the hammer or press will be forced to stand idle.

In these cases, the stock should be charged into the furnace in batches. The quantity of stock per batch will depend on the heating time and the duration of the hammer or press operation per forging.

THE BLACKSMITH'S WORKING PLACE

The working place of any blacksmith comprises the area of the forge shop directly adjacent to and surrounding the forging unit (hammer or press) at which he works. Correct organisation of the working place is of great importance in improving the labour productivity.

When organising the working place, the following chief rule must be always strictly observed: there should be nothing in the working place not needed during work; on the other hand, everything which is needed for work must be at hand. The basic equipment (hammer, furnace) as well as all auxiliary equipment (cranes, table, tool horse, etc.) must be so located as to obviate all unnecessary movement on the part of the blacksmith.

Fig. 291 shows the scheme of the organisation of the working place of G. Kovalenko's crew at the smith hammer in the forgeshop of the Uralmash Works; this can serve as an example of a correct, well thought-out organisation of a blacksmith's working place.

However, it should not be supposed that it is absolutely necessary to locate the equipment as shown in Fig. 291 in every case. Many other methods are possible and are practised for layin-gout the working place, depending on the type of equipment and the

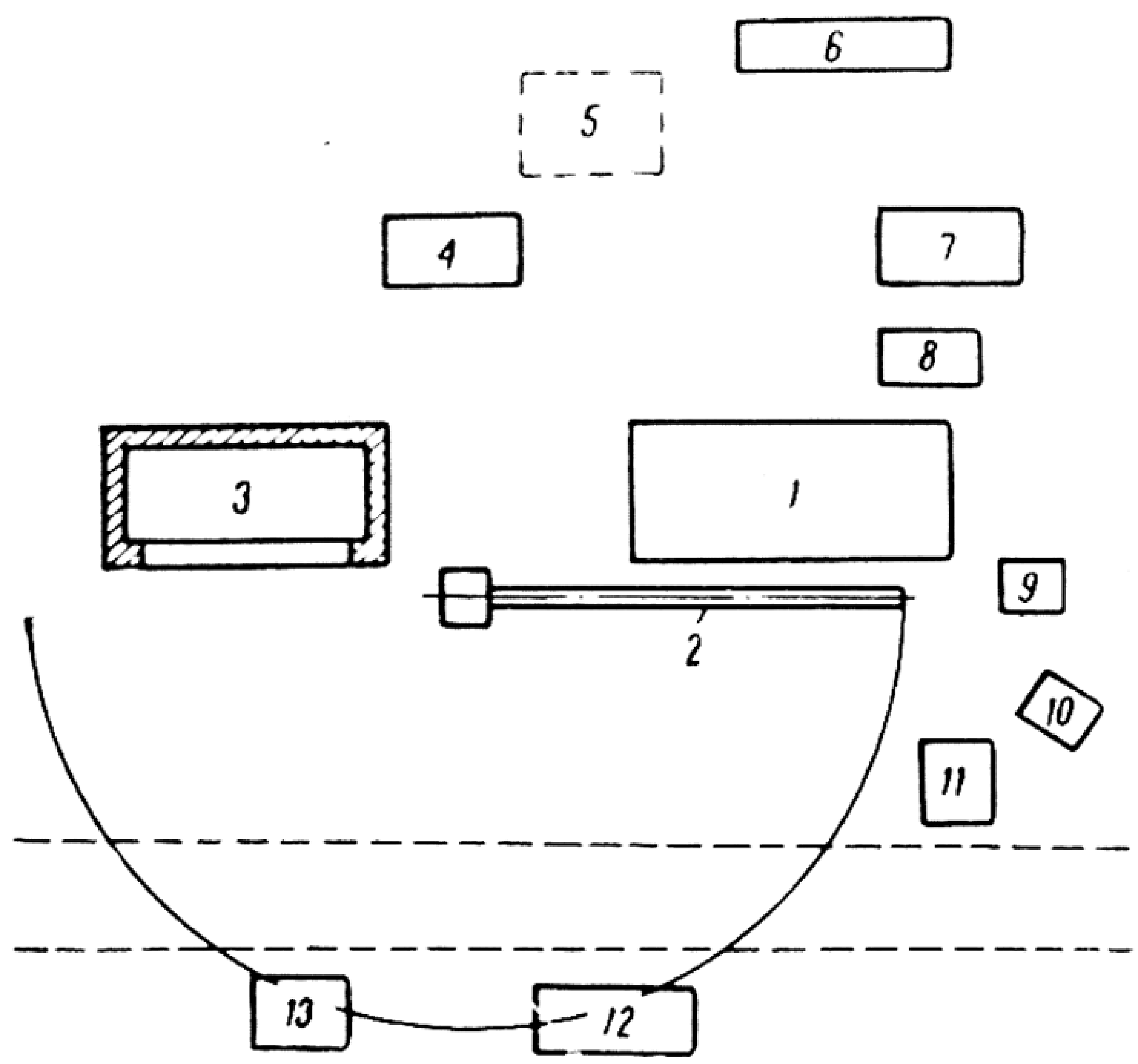


Fig. 291. Schematic diagram of working place organisation near a 3-ton smith hammer:

1) hammer; 2) bracket crane; 3) furnace; 4) scale box; 5) storage for heavy tools; 6) cabinet for light tools; 7) box for croppings; 8) water tank; 9) hammer operator's station; 10) blower fan; 11) table for measuring instruments; 12) inspector's table; 13) area for cooling forgings

kind of forgings to be made. Only the fundamental rule should always be borne in mind: it is imperative to ensure convenient and safe working conditions for the blacksmith and his crew.

The working place should always be well illuminated; exhaust hoods must be installed above each furnace, and all dangerous places must be protected by wire netting, etc.; in other words, the working place must meet all the requirements of the accepted safety engineering code.

All working tools and devices must be kept at every working place in such a way as to ensure their convenient handling and, moreover, to ensure free access to them at any time for examination and inspection. Tools which are in bad condition should never be kept together with those in good condition.

Blacksmiths never work without a crew of helpers. The composition of the crew always depends on the type of the hammer on which the blacksmith works, and the character of his work. As a rule, the crew should always consist of the same men. The blacksmith is the head of the crew, and his duties not only consist in carrying out his own work—he must also supervise the work of each member of his crew. He must always remember that he is entrusted with expensive and complicated equipment. And on his proper work depends the good condition of the equipment, the safety of the work, the fulfilment and overfulfilment of his task and, consequently, the wages of each member of the crew.

How, then, should a blacksmith work during the entire shift? On his arrival at the shop, he must, before commencing work, take over his working place clean and in perfect order from the previous shift, check the equipment and tools and, in case of any defects, immediately report them to the foreman. This done, he must get the task and the work sheet from his foreman and explain the work to be done to each member of his crew. Before commencing work, the blacksmith must count the pieces of stock and see that they are in proper condition for forging. As a rule, the previous shift must deliver the stock to the blacksmith's working place and charge the furnace with a sufficient number of pieces of stock to ensure that they are at the correct forging temperature by the time work is begun. The blacksmith then stations each member of his crew in his proper working place. And only after this does he give the order to the furnace operator to take out the stock from the furnace and place it on the anvil.

At the end of his shift, the blacksmith must put his working place in order and hand it over to the next shift. He may not leave the shop before the arrival of his relief and before handing his working place over to him. Should his relief fail to come to work (for instance, in case of sickness) the blacksmith may leave the shop only with the permission of his foreman.

RATE SETTING

So far the technology of forging practice has been discussed, without considering the question of how much time a blacksmith should take for making a definite forging.

How, then, can the quantity of forgings a blacksmith should produce per unit of time—say, per hour or per shift—be determined? This question is solved by what is called *rate setting*. Rate setting determines the time needed for a worker to execute a given piece of work so as to ensure its meeting all the engineering specifications.

Rate setting promotes: 1) increasing the productivity of labour; 2) reducing the cost of production, and 3) efficient planning of production.

Rate setting establishes *time standards* and *production standards*. By a time standard is understood the amount of working time necessary, under definite production conditions, for a worker of a given trade and of the proper grade of skill, working under correct conditions of labour organisation, to produce one unit of good-quality production. In the forging trade, the time standard is usually set for an entire crew. The time standard for a blacksmith's crew will be the sum of the time standards of all the members of the crew per unit of production. For instance, suppose that a definite job is to be executed by a crew of two men—by a blacksmith and a striker; and that this crew spends 0.5 hour for forging one bolt. According to what has already been said, each man will spend $\frac{0.5}{2}=0.25$ man-hour in forging one bolt.

The production standard is that amount of good-quality production (forgings, in this case) which should be produced per unit of time (per hour, or per shift) by a worker of the proper skill, with the given tools, under conditions of correct organisation of work. And it is necessary to distinguish between the production standard for one worker (blacksmith, blacksmith's striker) and the production standard for the entire crew.

The production standard for a blacksmith's crew is the quantity of production (forgings) which should be produced per unit of time (per hour, per shift) by the entire crew.

In order to calculate the shift production standard of the entire blacksmith's crew from the given time standard, the total working time of the entire crew must be divided by the time standard. For instance, suppose that the time standard for forging one shaft is 2 man-hours. The shaft is forged by a crew consisting of one blacksmith and two helpers. First of all, the number of shafts which the crew should forge in an eight-hour shift in order to fulfil its task by 100 per cent is calculated. The total working time of a blacksmith's crew during one shift will be $3\times8=24$ man-hours. The time standard for one shaft has been set at 2 man-hours; consequently, in 24 man-hours, i.e., during one shift, this blacksmith's crew should forge $\frac{24}{2}=12$ shafts to ensure the fulfilment of its task by 100 per cent.

INSTRUCTION CHART 1

Rational Method for Charging and Discharging Stock into and from Heating Furnaces

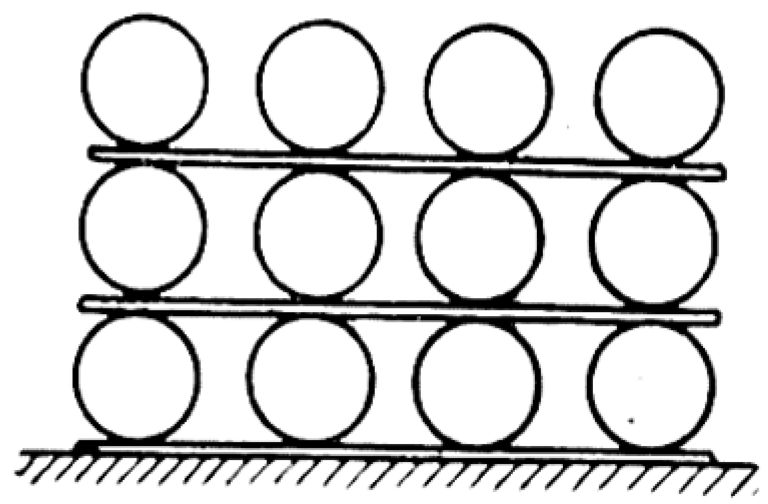
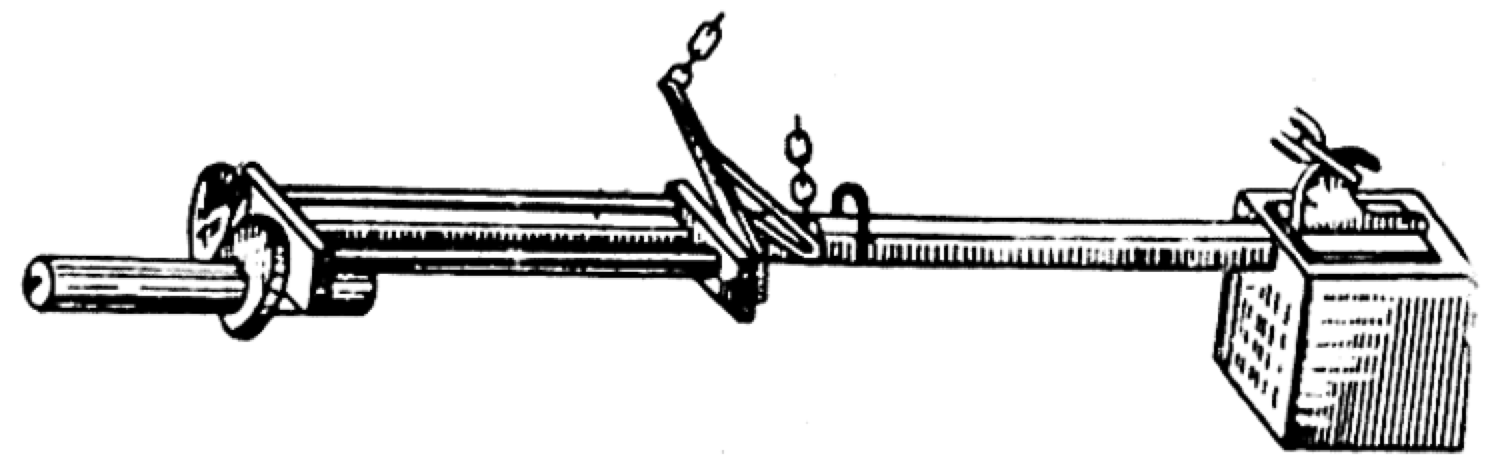
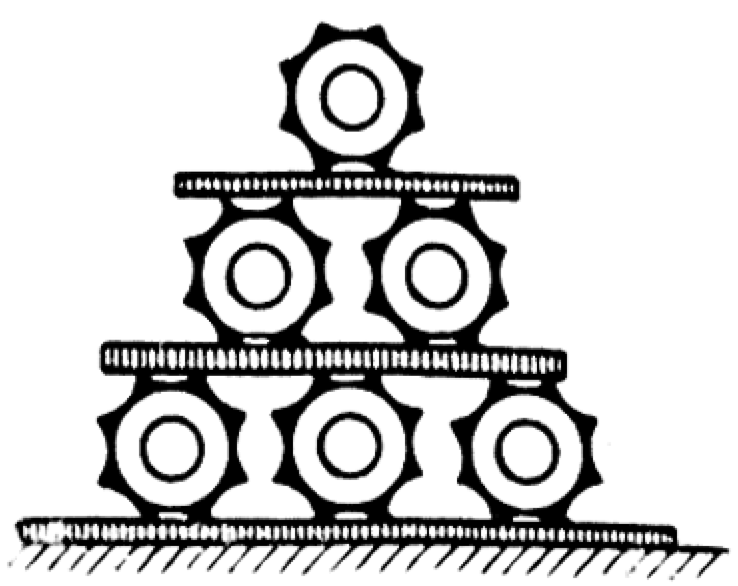
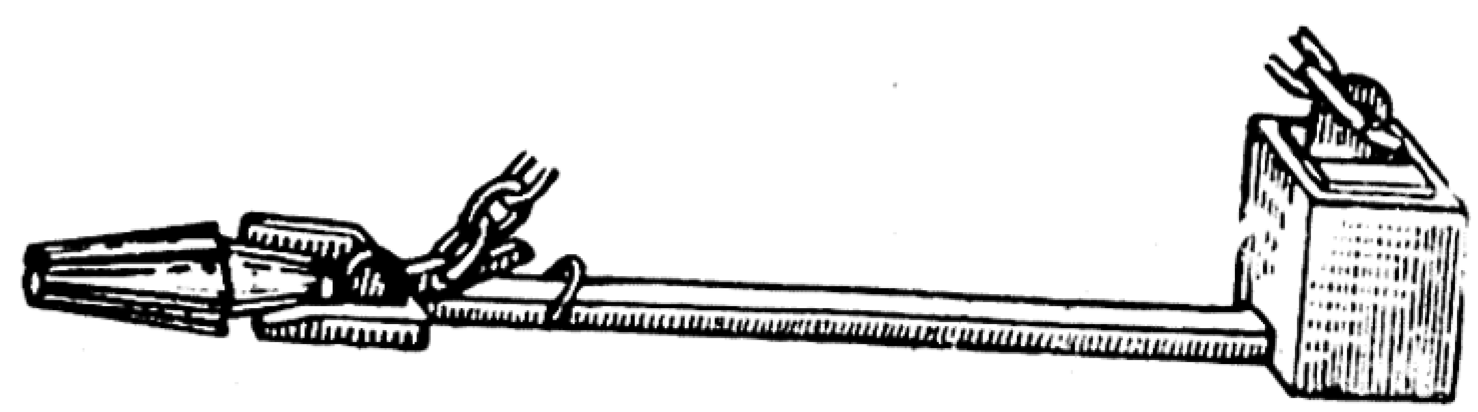
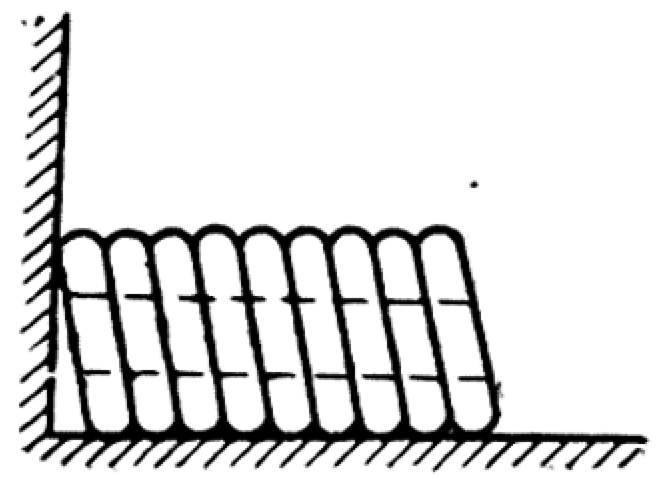
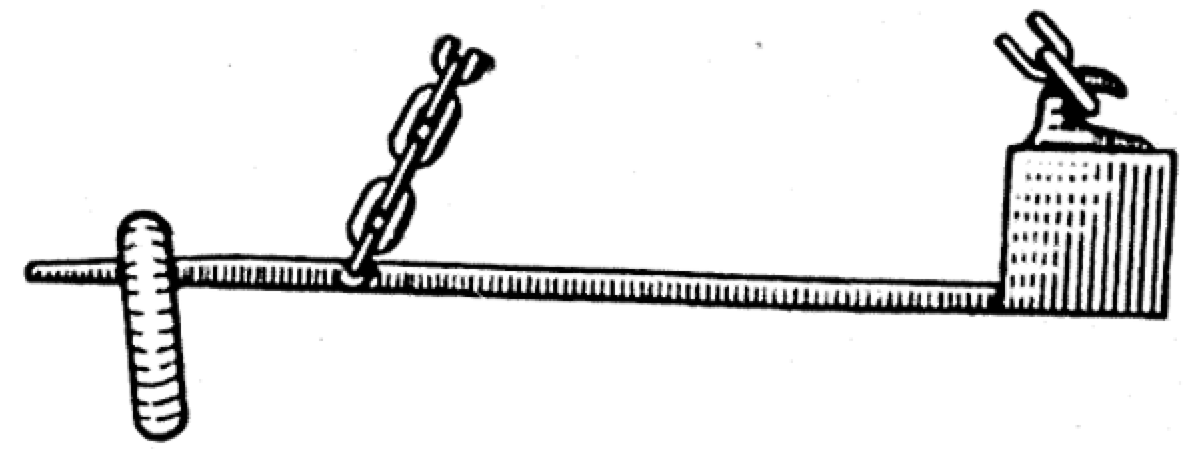
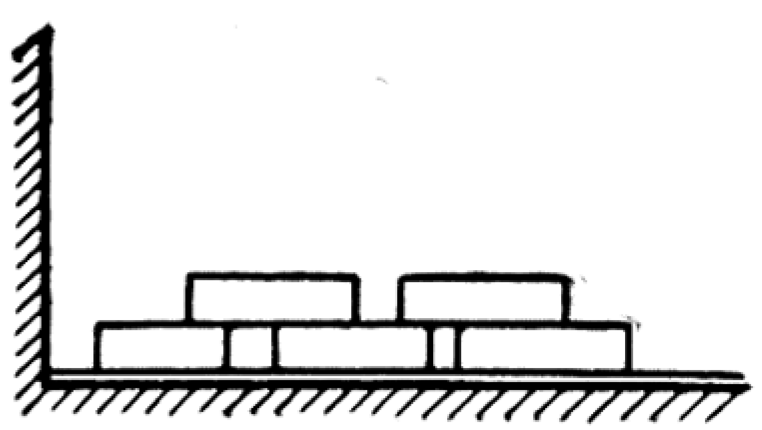
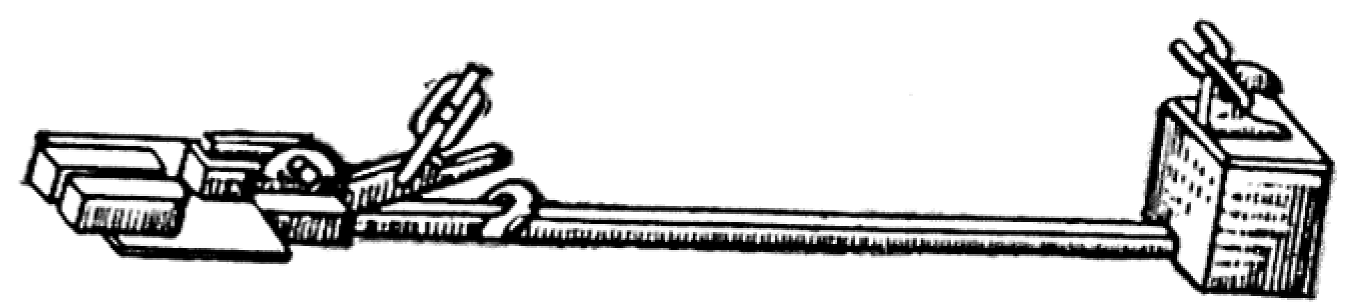
No	Type of stock	Scheme of charging stock into furnace	Furnace charging and discharging fixture	Furnace charging and discharging rules
1	Bar stock, round and square, from 2 to 4 m long			Charge bars into furnace with minimum clearance of 0.25 of their diameter or thickness. Each row of bars must be stacked on supports; dimension of supports: a) on hearth of furnace—not less than 80 mm in diameter; b) between rows of bars—not less than 60 mm in diameter. Number of supports per row—not less than two. Bars to be charged into and discharged from furnace with the aid of a special charging fixture
2	Ingots up to 1.6 tons in weight			Charge ingots into furnace as shown in sketch. Supports to be not less than 60 mm diameter each. Number of supports per row—not less than two. Ingots to be charged into, and discharged from furnace with aid of charging fork lever

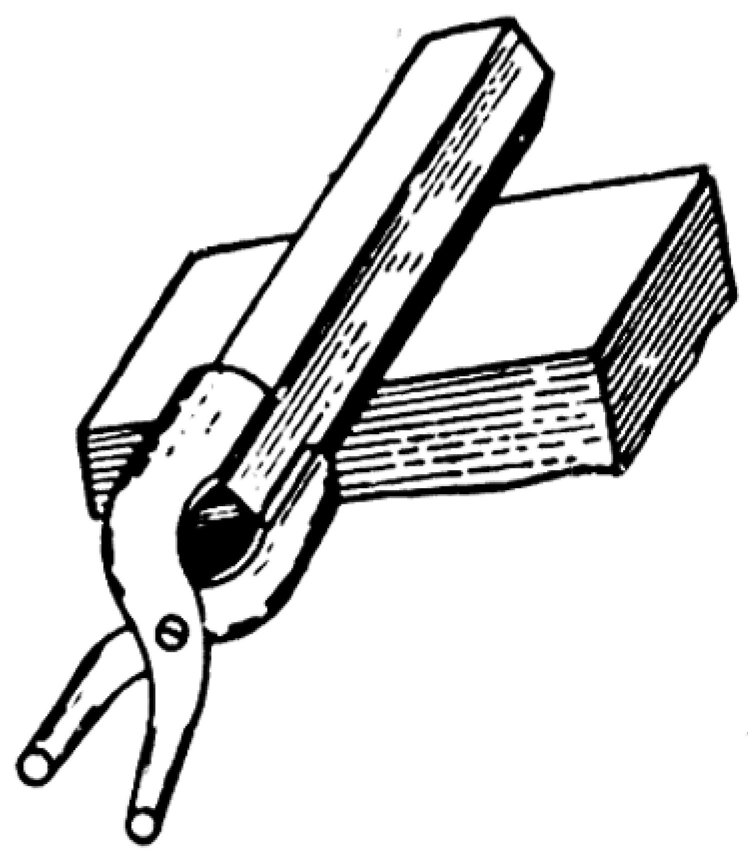
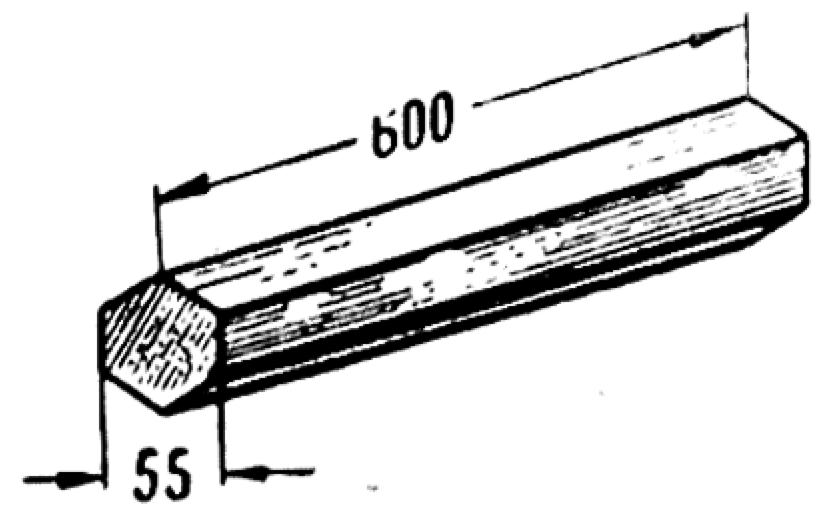
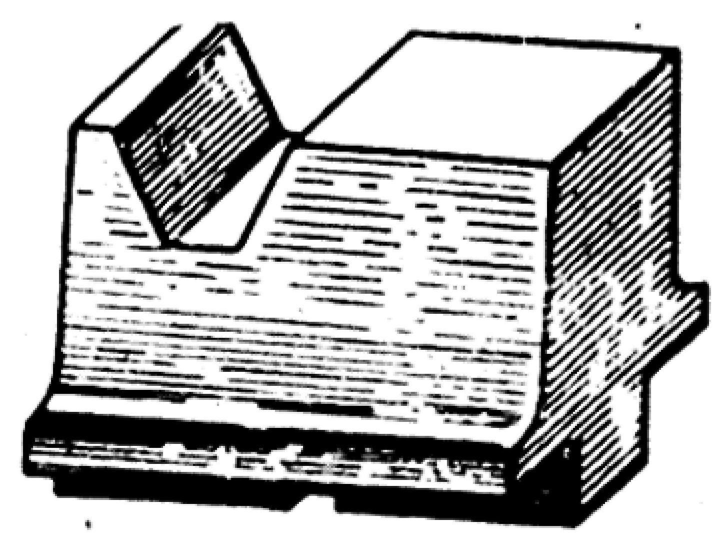
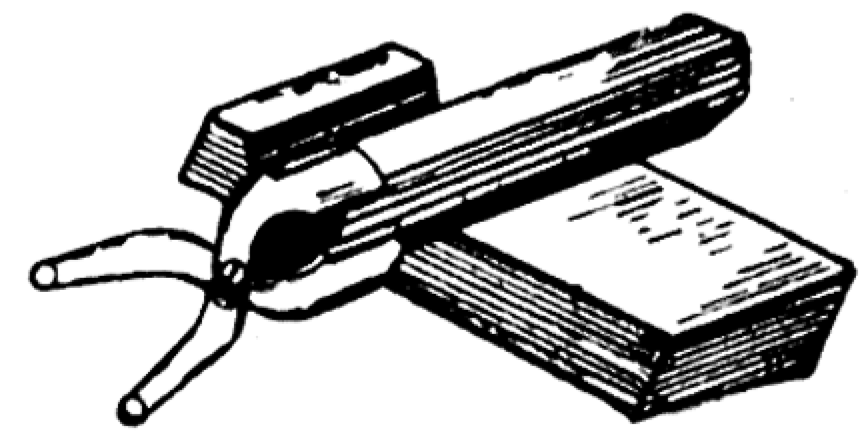
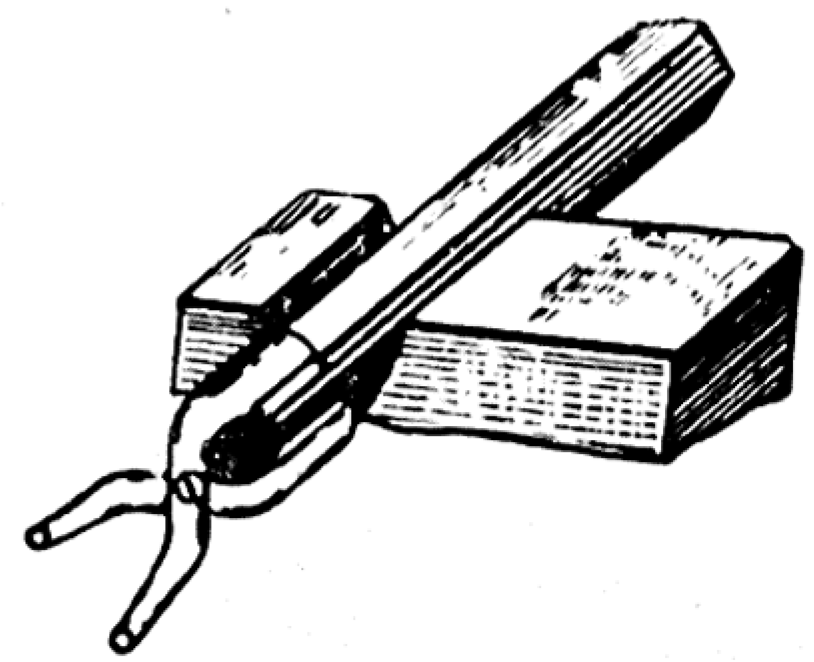
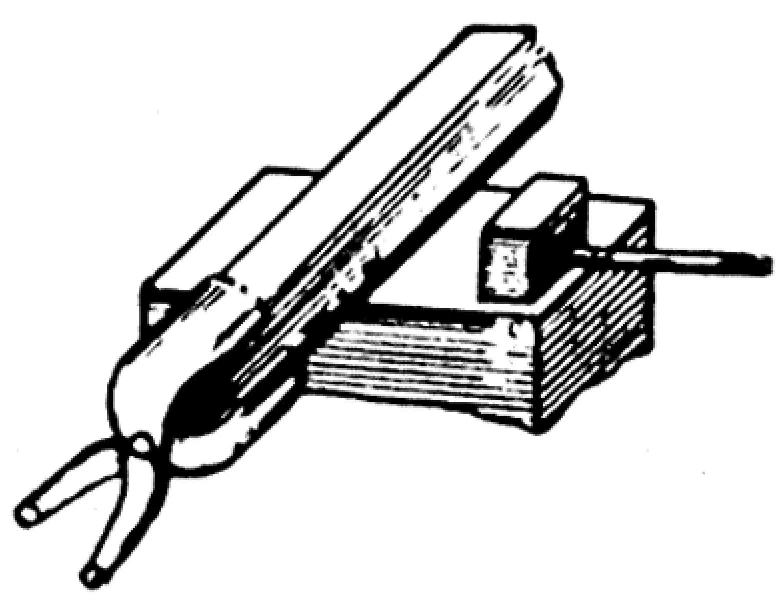
CHART 1 (continued)

No	Type of stock	Scheme of charging stock into furnace	Furnace charging and discharging fixture	Furnace charging and discharging rules
3	The blanks for rolling			Stack tire blanks to be rolled on furnace hearth according to sketch. Charging and discharging to be effected with the aid of charging bar
4	Stock cut in length up to 800 mm			Charge cut stock up to 800 mm long into furnace with charging fork and special fixture; they must be handled so that each piece of stock can be taken up separately; remove the stock from the furnace with the aid of a special charging fixture

INSTRUCTION CHART 2

Complex Forging Technological Process for Forging Hexagonal Bar According to Old Technology

Specifications of work:
Weight of forging—12.74 kg
Weight of stock—13.2 kg
Dimensions of stock—diameter 80 mm
$l = 393 + 5$ mm
Material—steel grade 40
According to complex technology

Sketch of pass	Forging operation	Time in minutes	Sketch of forging and of special die	Sketch of pass	Forging operation	Time in minutes
	Forge stock between flat top and bottom dies		 		Forge stock on flat face of die	
					Finish forging to size; straighten forging in special impression in bottom die	
					Total time required	40
	Finish to size, straighten; tools used—stop, flat top and bottom dies					
	Total time required	45				

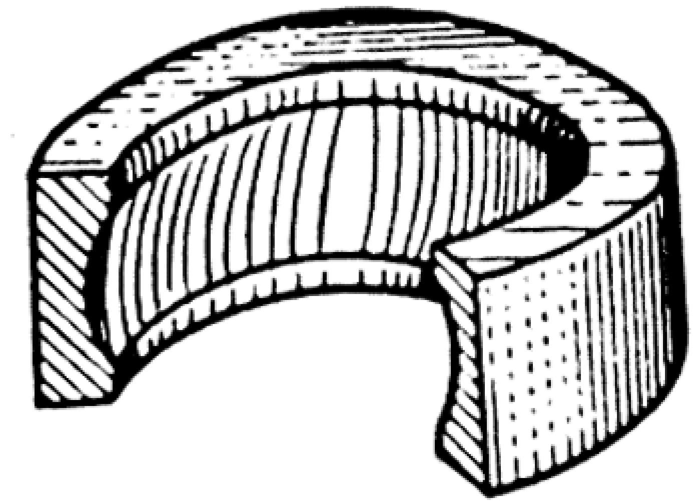
Engineering instructions:

Excellent quality of the forging can be ensured using the impression in the bottom die. The depth of this impression is equal to the required distance between the opposite sides of the hexagonal bar.

Tools: hot set, tongs and special bottom die

CHART 3

Technological Process of Forging Ball-Bearing Ring



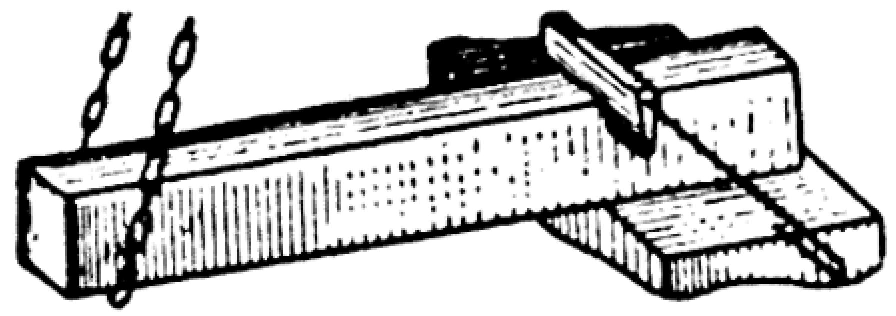
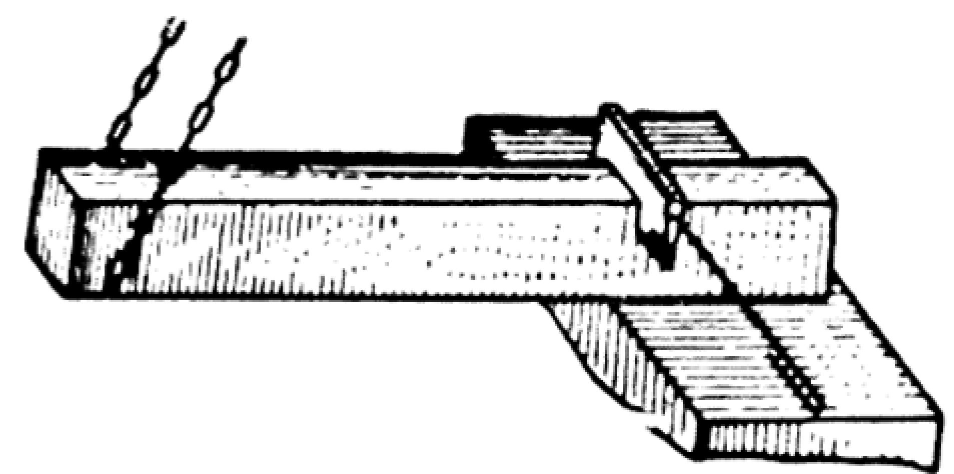
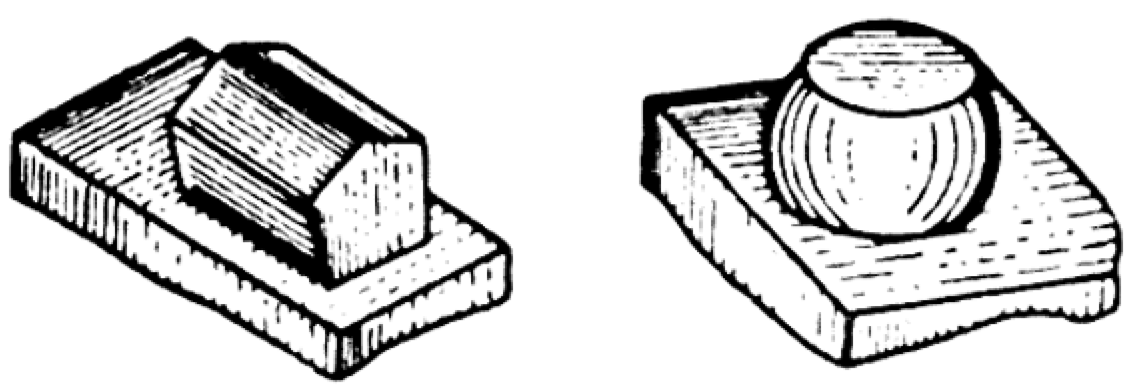
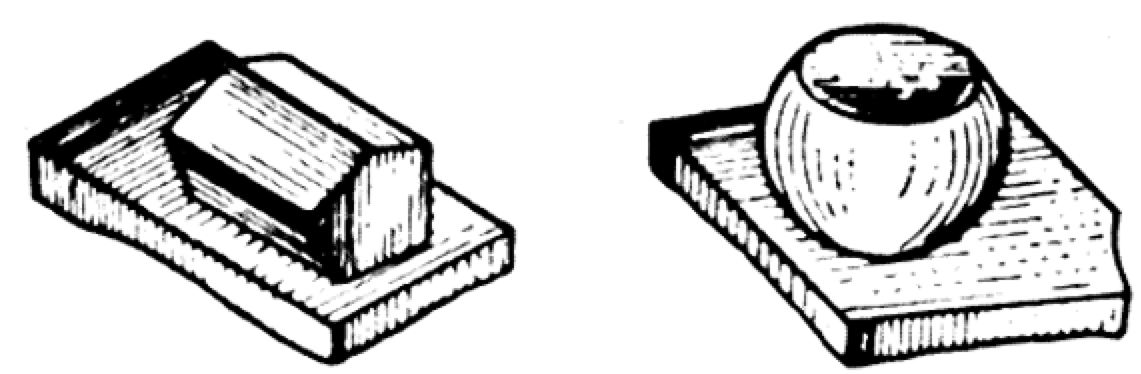
No	Old method of forging		No	Complex Technology	
	Description of operations	Sketch of pass		Description of operations	Sketch of pass
1	Place bar-stock on bottom die of hammer and cut off required length of stock		1	Place bar on bottom die of hammer and cut off required length of stock	
2	Round edges and upset		2	Round edges and upset	

CHART 3 (continued)

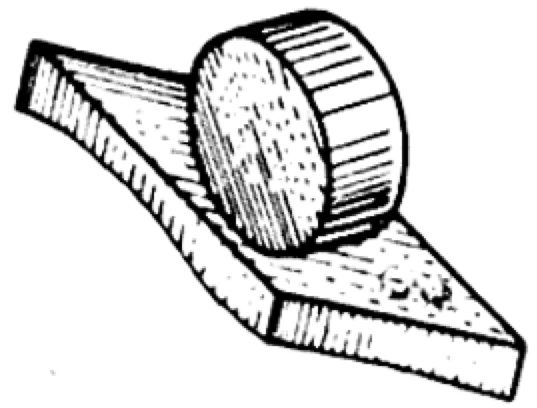
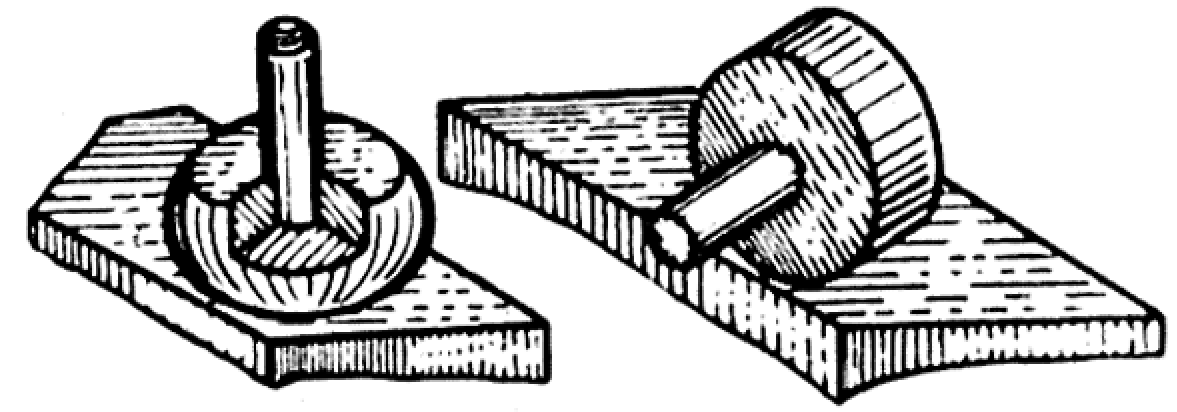
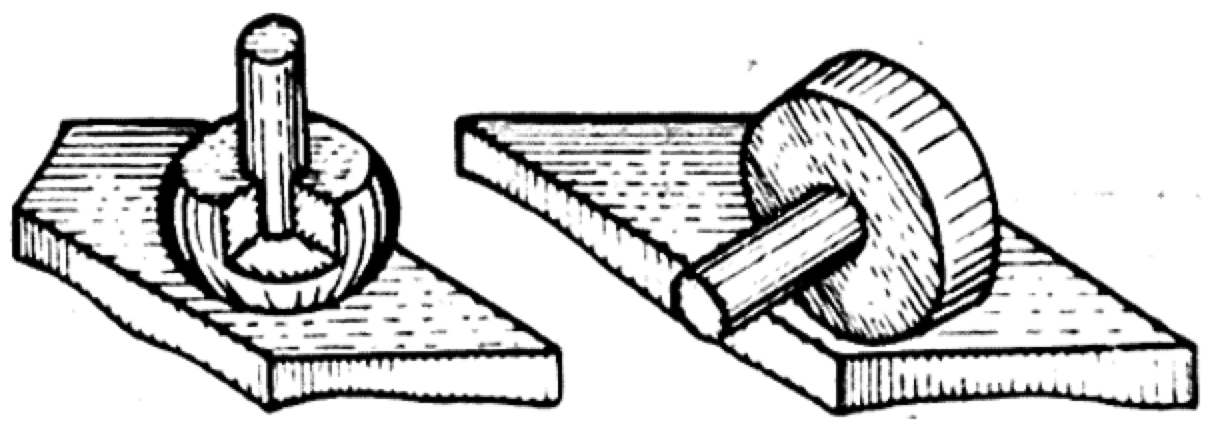
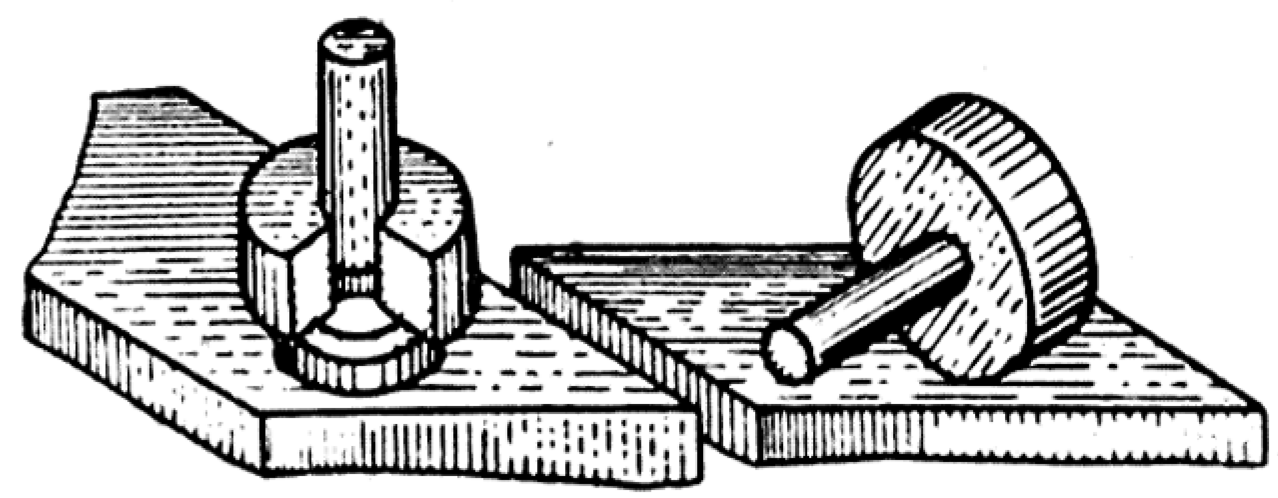
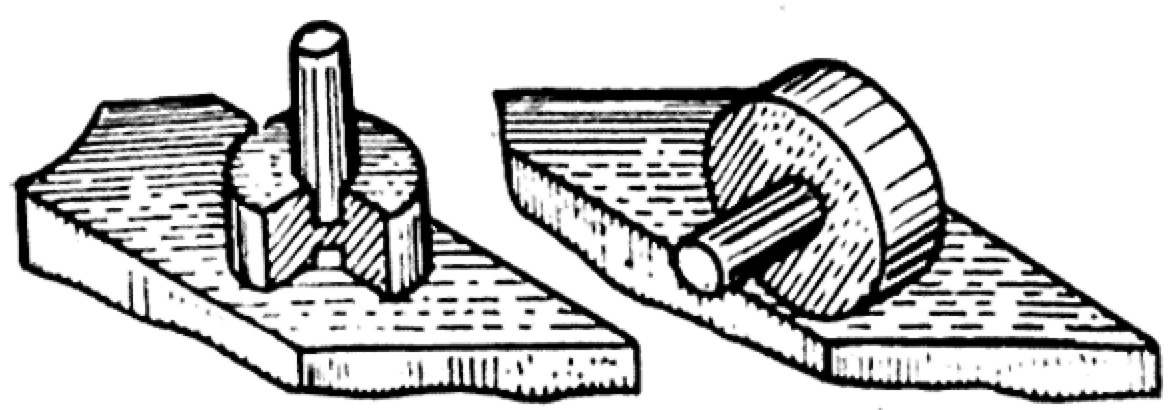
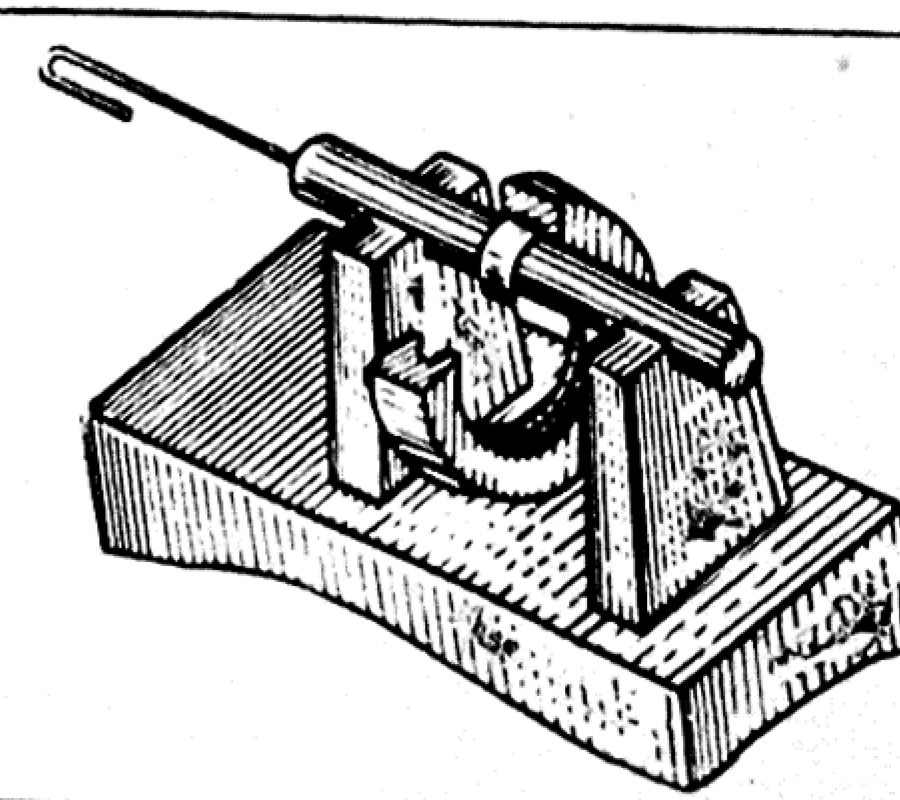
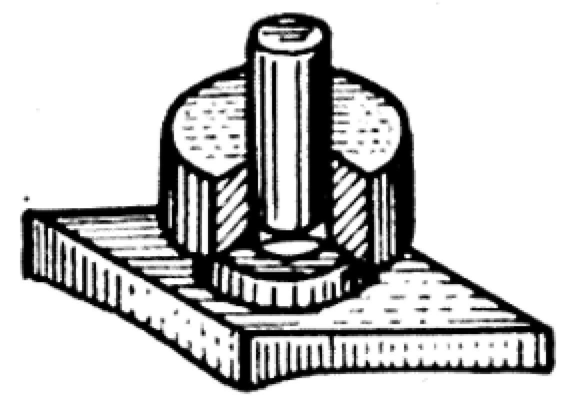
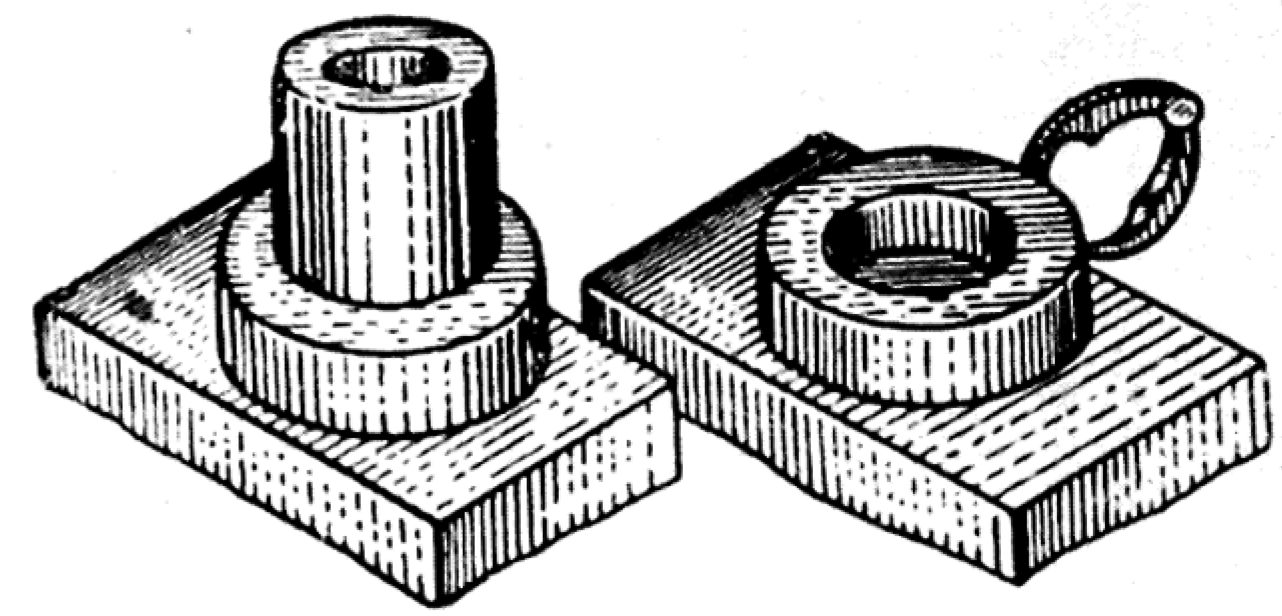
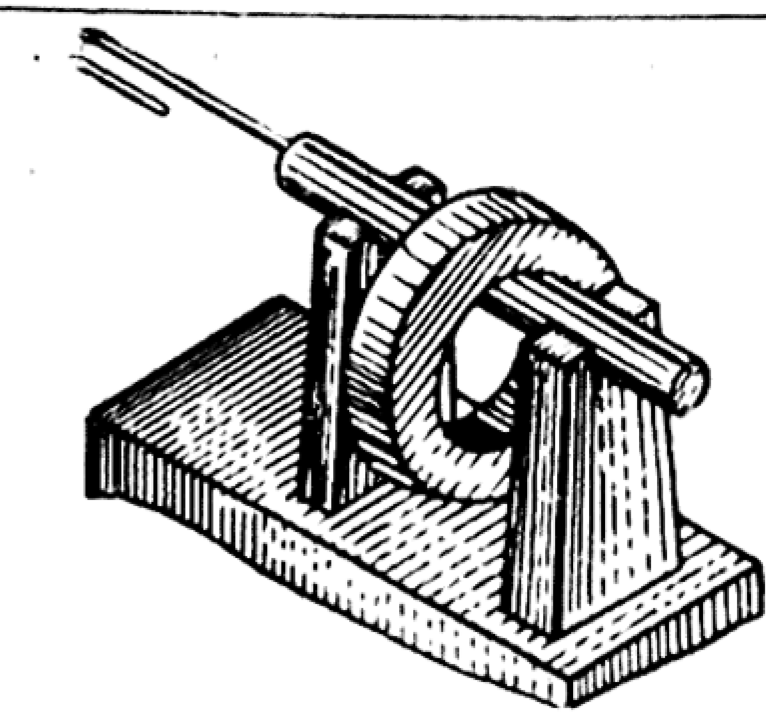
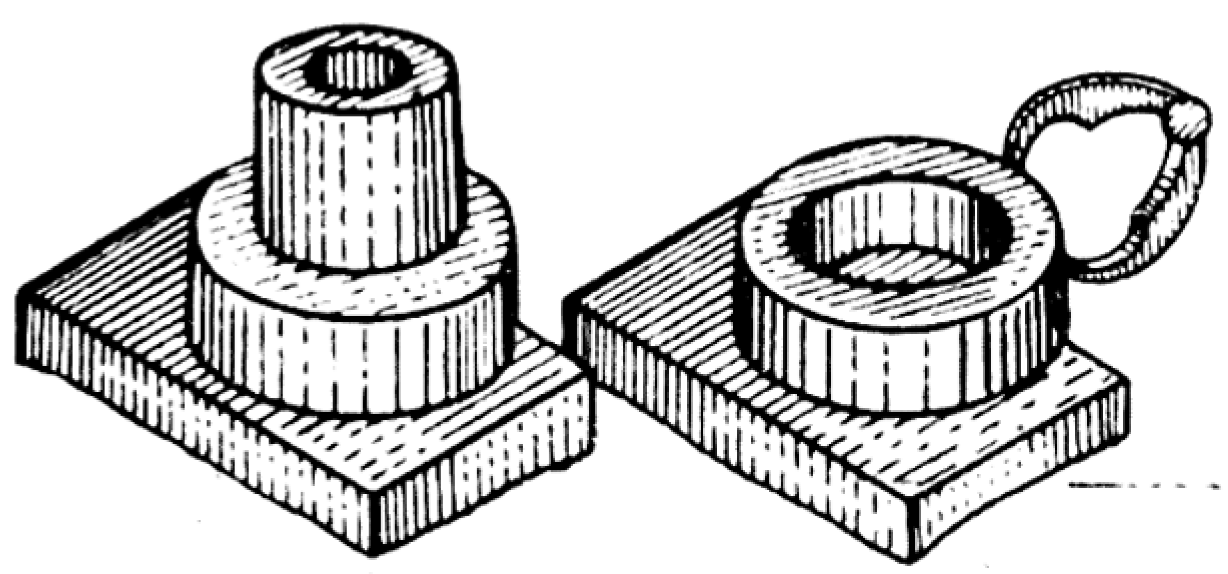
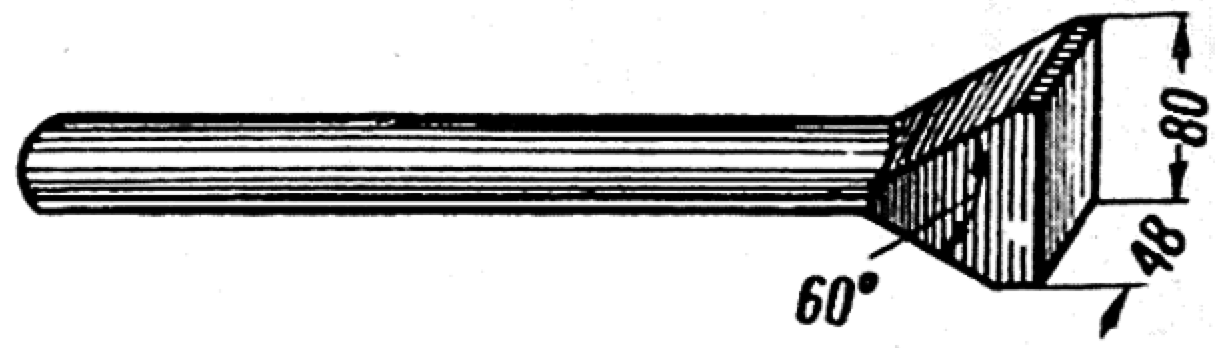
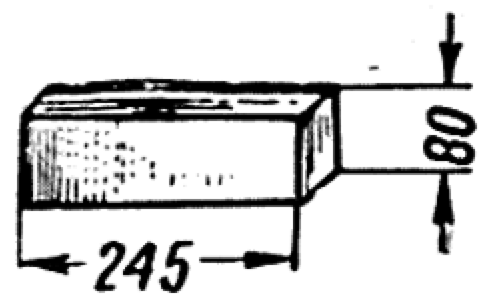
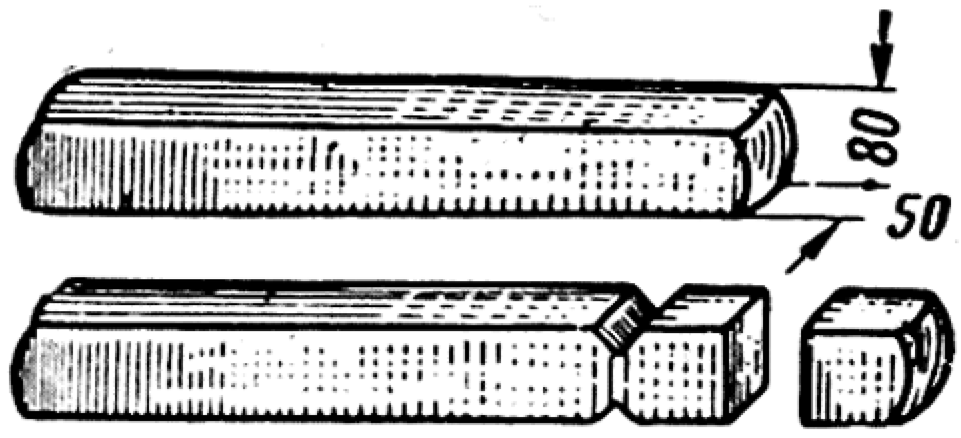
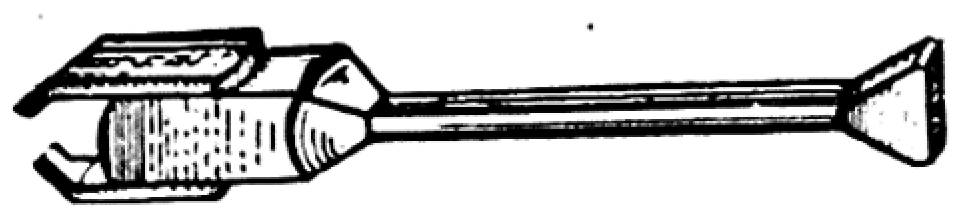
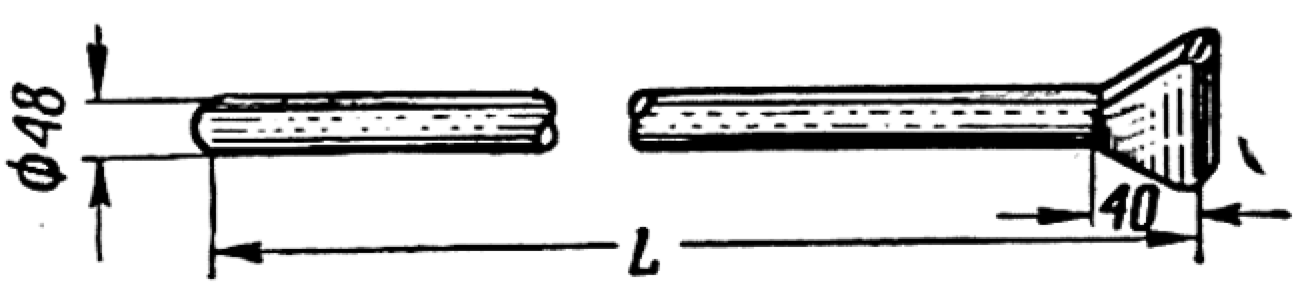
No	Old method of forging: Description of operations	Old method of forging: Sketch of pass	No	Complex Technology: Description of operations	Complex Technology: Sketch of pass
3	Hammer circumference of stock		3	Punch hole from one side. Hammer circumference of stock	
4	Punch hole from one side, hammer circumference of stock		4	Punch hole from opposite side. Hammer circumference of stock	
5	Punch hole from opposite side. Hammer circumference of stock		5	Roll (spread) forging on shaped mandrel	

CHART 3 (continued)

No	Old method of forging		No	Complex Technology	
	Description of operations	Sketch of pass		Description of operations	Sketch of pass
6	Finish punch hole and eject slug		6	Straighten face and bring to correct diameter. Check dimensions of forging	
7	Roll ring			*Economical effect:* 1. 3 kg of steel per ring economised as a result of forging ring with recess for balls. 2. Productivity of labour increased by 16 per cent as a result of eliminating operation No. 3 (hammering circumference of ring) and operation No. 6. The hole is punched with punch of larger diameter. 3. Machining operations reduced	
8	Straighten face and bring to correct diameter. Check dimensions				

Technological Process



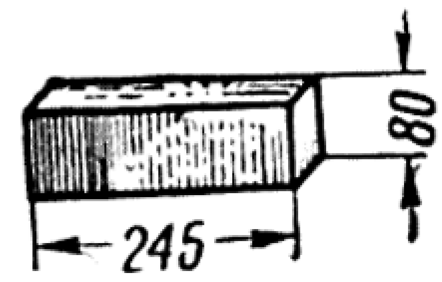
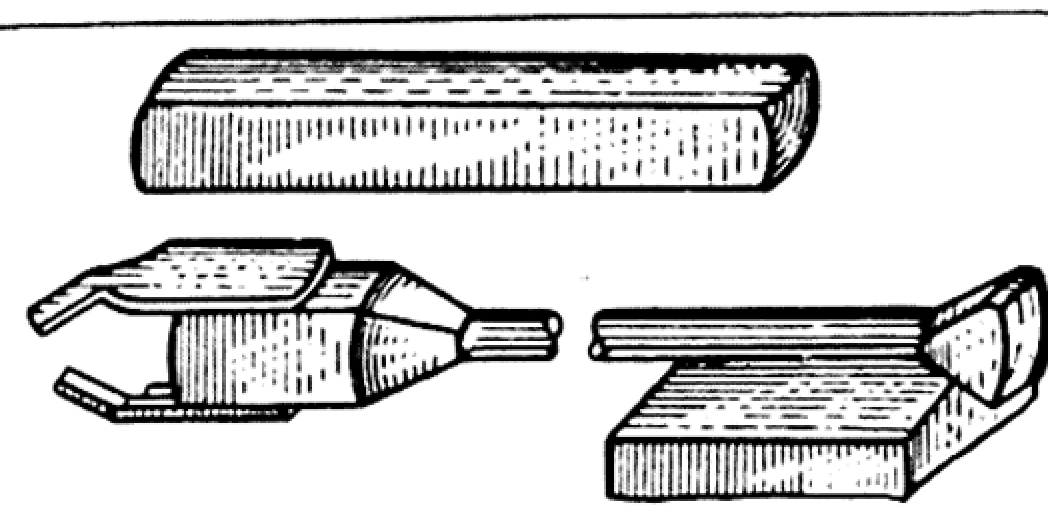
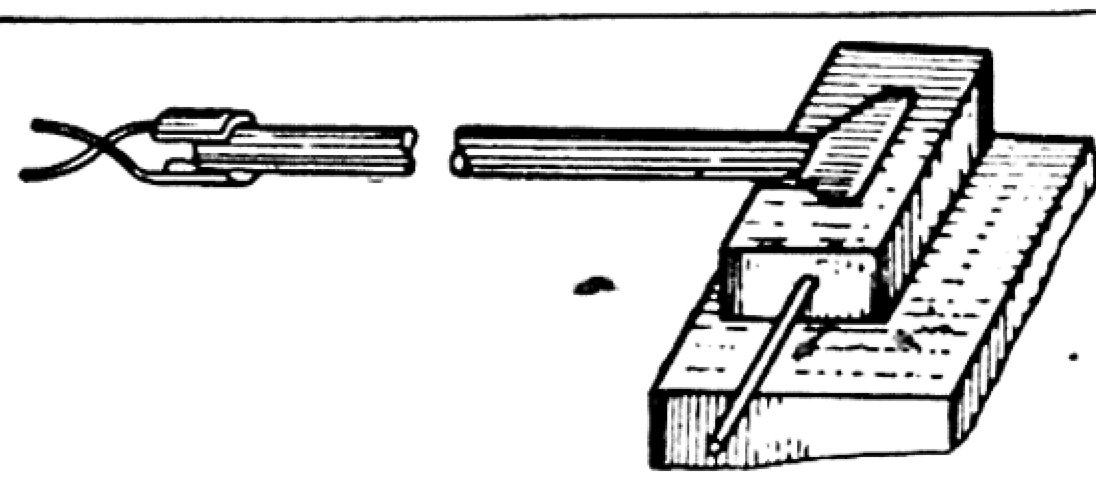
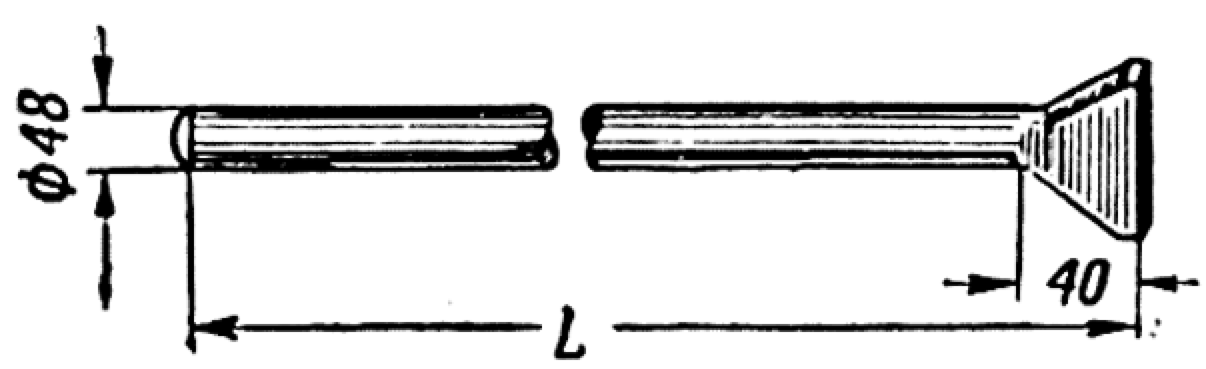
No	Old method of forging bolt		
	Description of operations	Sketch of pass	Time required
	Stock		
1	Draw-out 80 mm diameter stock to flat bar 50×80 mm; set with side-set and crop off surplus metal		
2	Rough draw-out central section of stock and then swage to 48 mm diameter		
3	Draw-out opposite end of forging; smooth out entire length of shank to diameter 48 mm in swage; swage head		

Average total time—10 minutes	
How to ensure excellent quality of production	How to ensure efficient utilisation of equipment
1. Heat steel to temperature not less than 1180° C; 2. Before starting work, warm bottom swage to 150° C; 3. See that the head of the cutting tool is properly cleaned	1. Conduct forging between centre of dies 2. Keep bottom die free from scale

of Forging Bolt

CHART 4

Specifications: Weight of forging— 12.0 kg.
Material—steel grade Cr. 3

No	Complex technology		
	Description of operations	Sketch of pass	Time re-quired
	Stock		
1	Draw-out stock to bar of 50×80 mm cross-section. Marking metal for forming head, draw-out centre of bar between top and bottom dies		
2	Draw-out opposite end, swage to 48 mm diameter. Stamp head of bolt in special bottom swage		
3	Trim flash in special bottom trimming die, employing tapered set for shaping head		

Average total time — 6.5 minutes

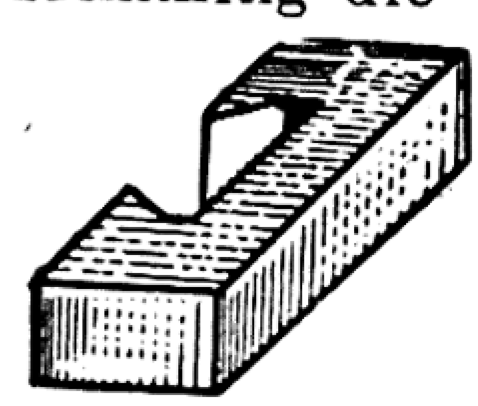
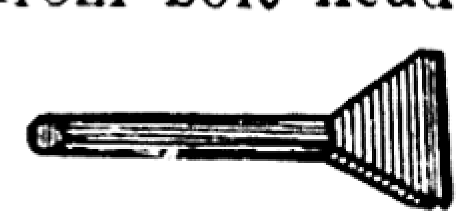
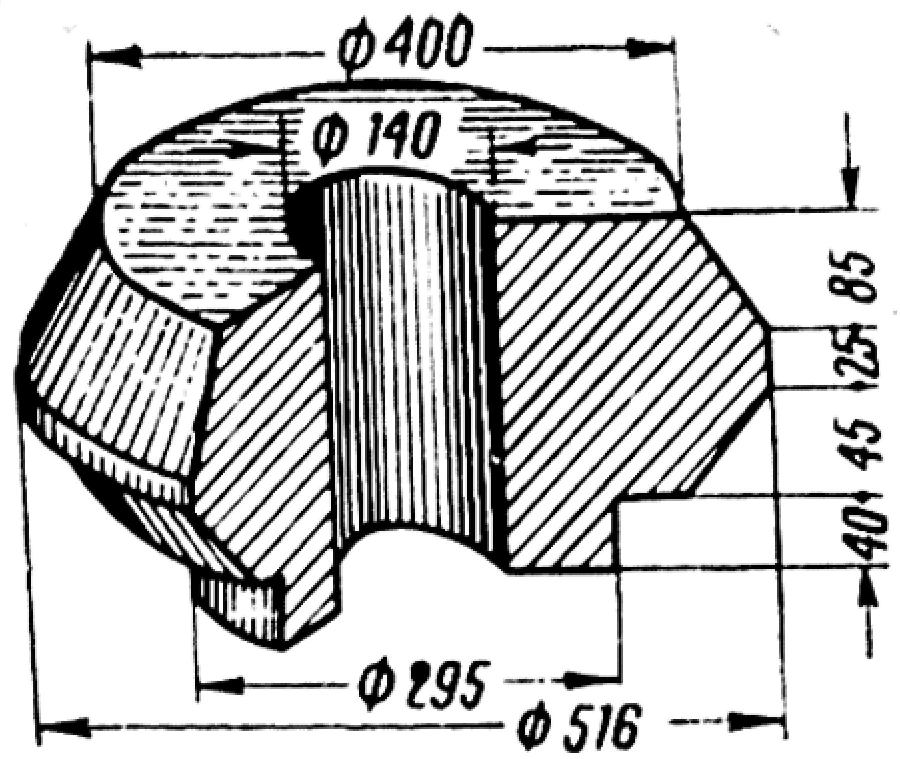
Economy due to introduction of complex technology	Tools and fixtures used	Sketch of new fixture
1. Forging by new method eliminates operations of rough forming head, cropping off surplus metal and swaging head; 2. Quality of work is considerably improved and uniform dimensions for all bolts are ensured; 3. Productivity of labour increased by 35 per cent; 4. Economy 1 kg of steel per bolt	1. Flat tongs, round tongs, 48 mm diameter swage 2. Bottom swage; trimming die 3. Taper set; hotset	Trimming die  Taper set for trimming flash from bolt head 

CHART 5

Technological Process for Forging Bevel Gear Blank



Specifications of forging:

1. Weight when forged by old process — 322 kg;
2. Weight when forged by new process — 282 kg;
3. Material — steel grade 50;
4. Capacity of forging hammer — 5 tons

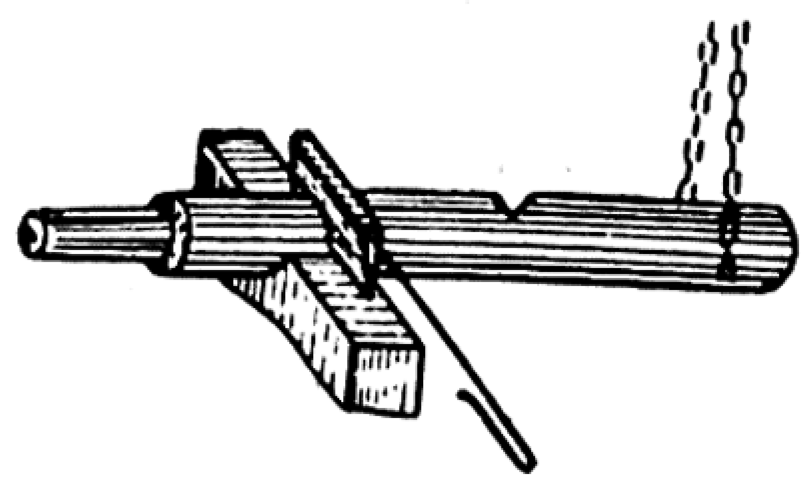
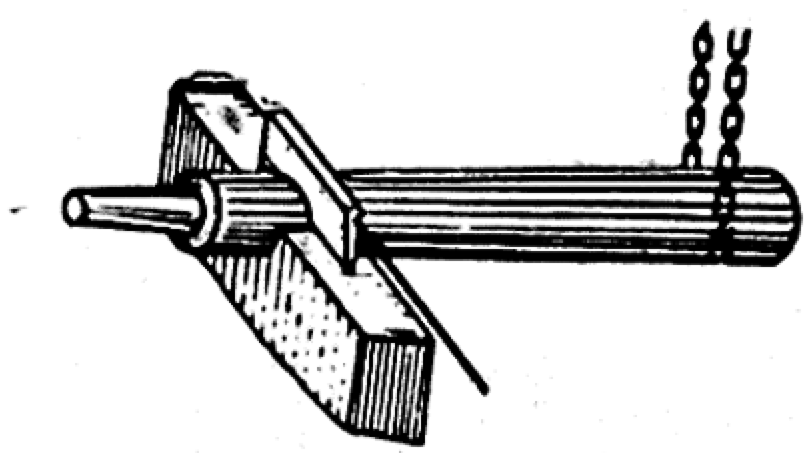
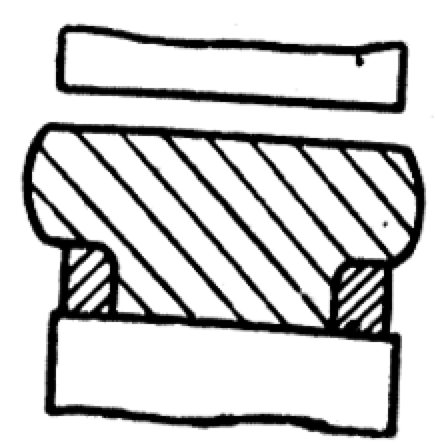
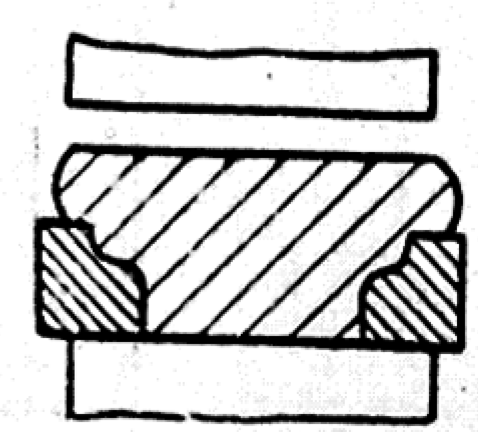
No	Old method		No	Complex technology	
	Description of operations	Sketch of pass		Description of operations	Sketch of pass
1	Take bar from furnace and place on bottom die of hammer with the aid of charging fork. Cut to stock-lengths and simultaneously draw-out one end of each piece		1	Take bar from furnace and place on bottom die of hammer with the aid of charging fork. Cut to stock lengths, draw-out one end of each piece before cutting off second piece of stock	
2	Upset in bolster ring to dimensions specified in process chart		2	Rough upset in taper-hole bolster ring to dimensions specified in process chart	

CHART 5 (continued)

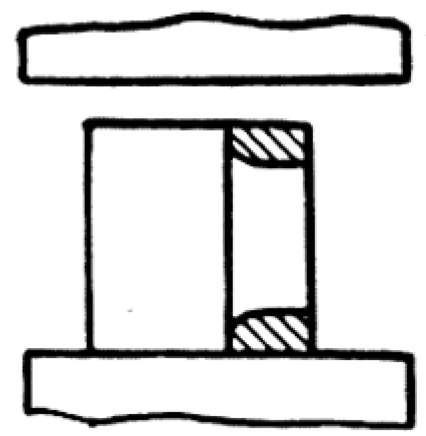
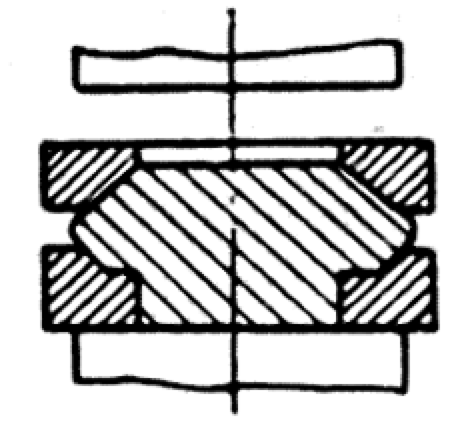
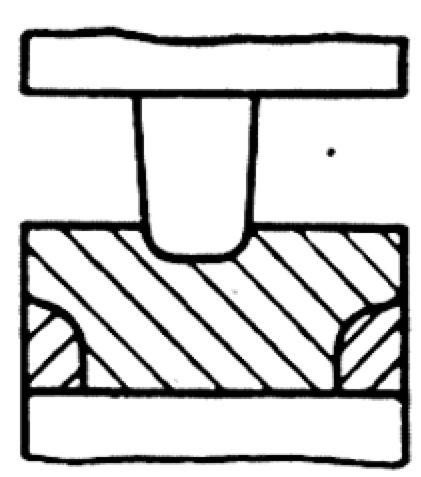
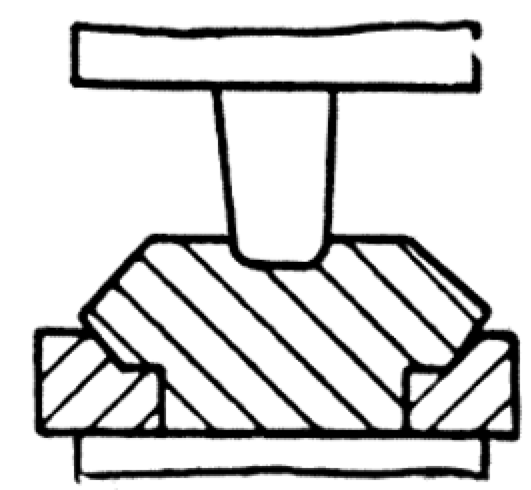
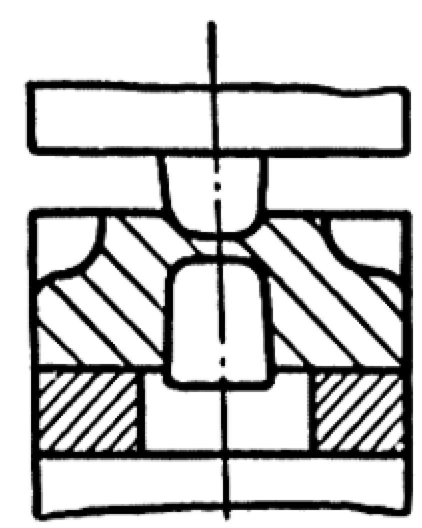
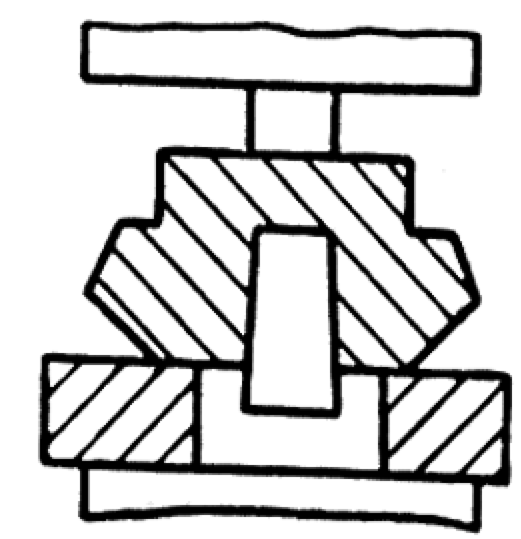
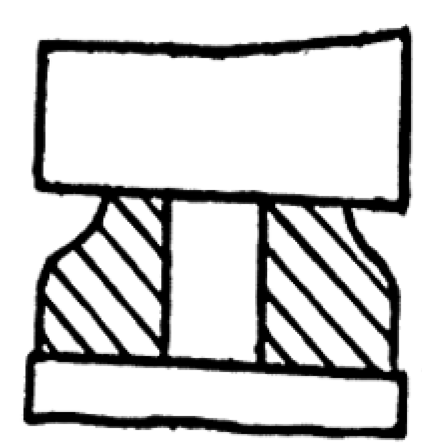
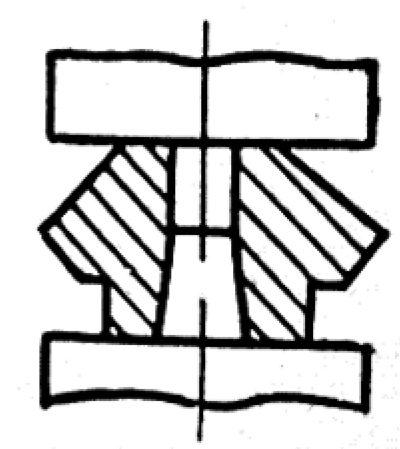
Old method				Complex technology		
No	Description of operations	Sketch of pass	No	Description of operations	Sketch of pass
3	Hammer circumference together with ring		3	Place top taper-hole upsetting ring over the forging and finish upset	
4	Punch hole from one side with 120 mm diameter punch without removing forging from ring		4	Remove top ring. Punch hole with 150 mm diameter punch. Withdraw the forging from bolster ring	

CHART 5 (continued)

No	Old method: Description of operations	Old method: Sketch of pass	No	Complex technology: Description of operations	Complex technology: Sketch of pass
5	Punch hole in opposite side of blank; remove punch from hole; remove forging from upsetting ring		5	Finish punch hole from opposite side; withdraw forging from upsetting ring	
6	Finish forge to height, check dimensions		6	Finish forge to height, check dimensions	

Rational organisation of working place:

1. To avoid extra setting up and adjustments of dies, it is recommended to forge the gear blanks in lots

To ensure excellent quality of production:

1. Always check the diameter of the bar-stock before marking it for cutting to stock-lengths;
2. Before cutting off lengths for each forging after marking out, notch the bar to stock lengths so as to ensure the required volume of each stock;
3. Cut stock from four sides;
4. See that flange of forging is properly upset, by rotating forging together with ring round its axis

To ensure better utilisation of equipment and how to preserve it in best condition:

1. Always heat the upsetting rings before starting work;
2. Avoid eccentric hammer blows;
3. Maintain forging temperature interval: 1,200°-750°C

Economy resulting from introduction of complex technology:

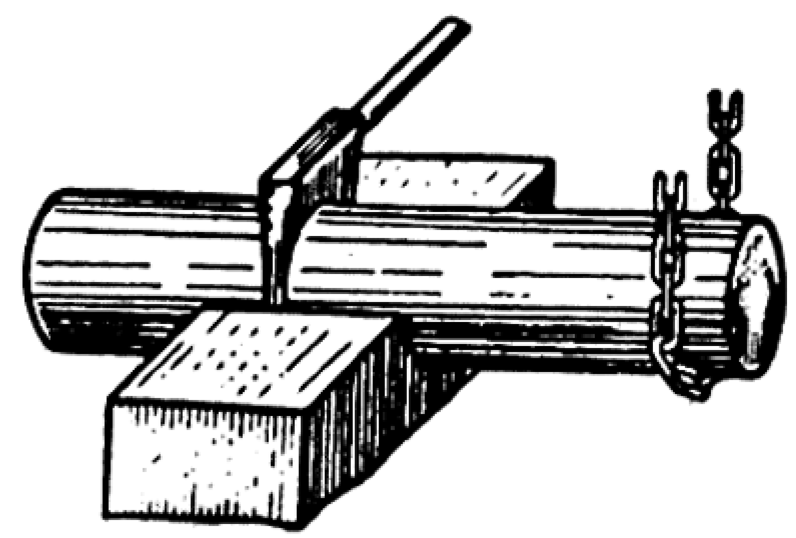
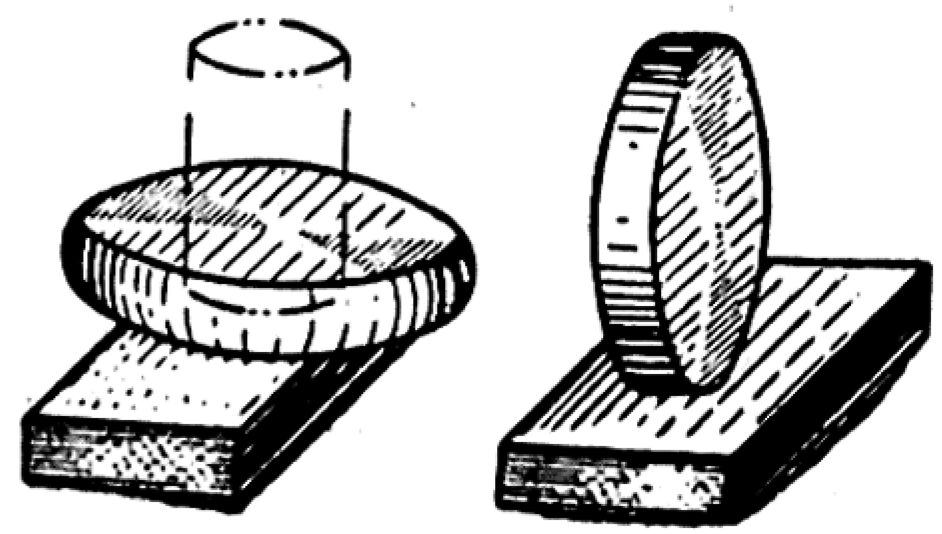
1. Steel is economised as a result of upsetting flange between top and bottom rings and increasing diameter of hole;
2. The upsetting process is speeded up as a result of reducing the volume of the flange and upsetting from both sides; the operation of hammering of the forging is eliminated;
3. Time is saved in machining the forging;
4. Fuel is saved as a result of reduction of the weight of the forging;
5. Weight of steel saved per forging: 40 kg

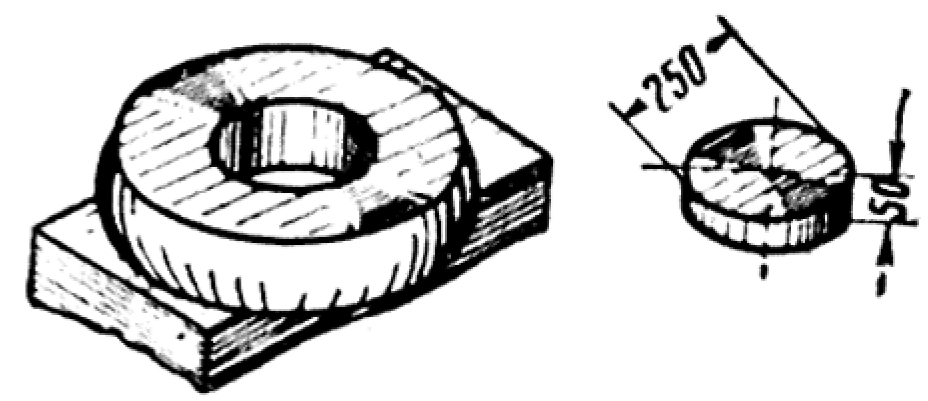
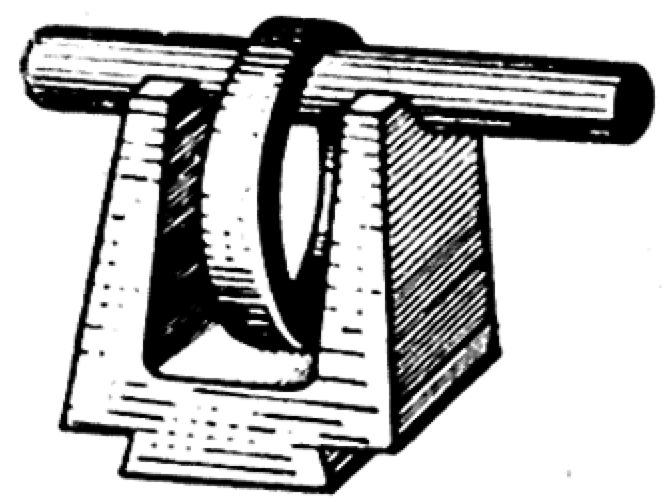
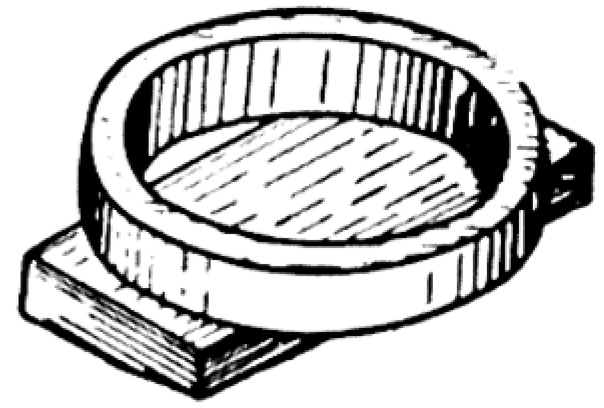
CHART 6

Technological Process for Forging Rotor Ring
Forging Temperature Interval: 1,130-800°C

Specifications of forging: Weight of forging 440 kg.
Weight of stock 500 kg.
Material: Steel — grade ШХ15СГ
No. of heatings required: 4

Old method

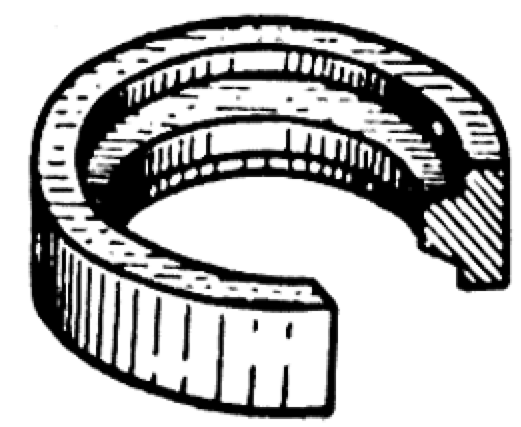
No.	Description of operation	Sketch of pass	Tool	Average time
1	Place heated bar onto bottom die of hammer. Cut off stock to length, gather cut stock and charge into furnace	 Heat to 1130°C.	Flat top die, bottom recessed die, hot set, side-cutter, levers, rule, calipers	4 minutes
2	Place stock on bottom die of hammer; upset; hammer circumference of upset stock; pierce hole		Flat top and bottom dies; 250 mm diameter punch; rule, calipers	10 minutes 40 seconds

		 Heat to 1130°C		
3	Place stock on bottom die of hammer; spread to forging dimensions, remove from hammer and charge into furnace for reheating		Special dies, mandrel, levers, rule, calipers	17 minutes
4	Place stock on bottom die of hammer, flatten faces to height, check dimensions		Flat top and bottom dies, bars, levers, rule, calipers	3 minutes 30 seconds

Total time: 35 min. 10 sec.

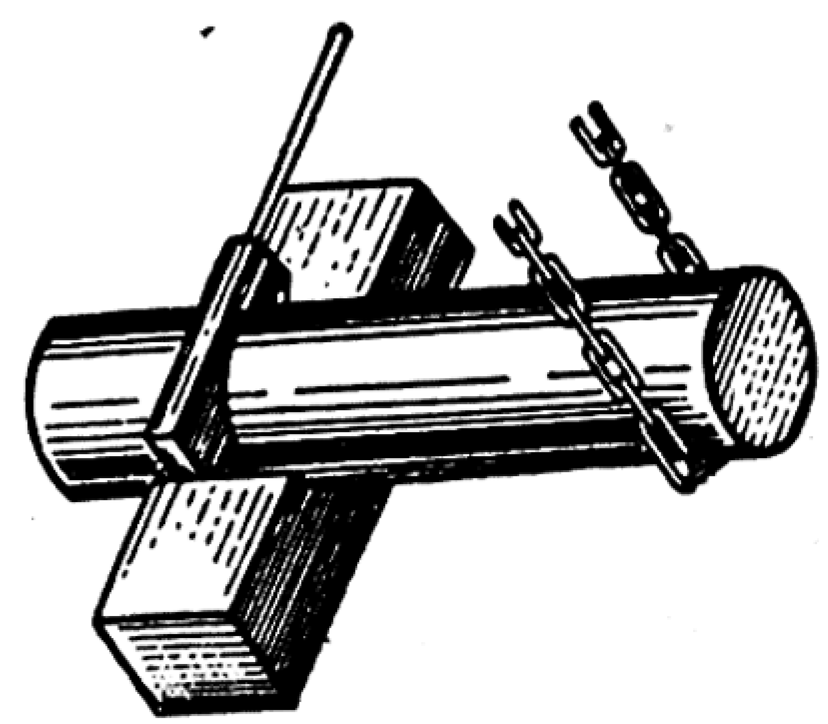
CHART 6 (continued)

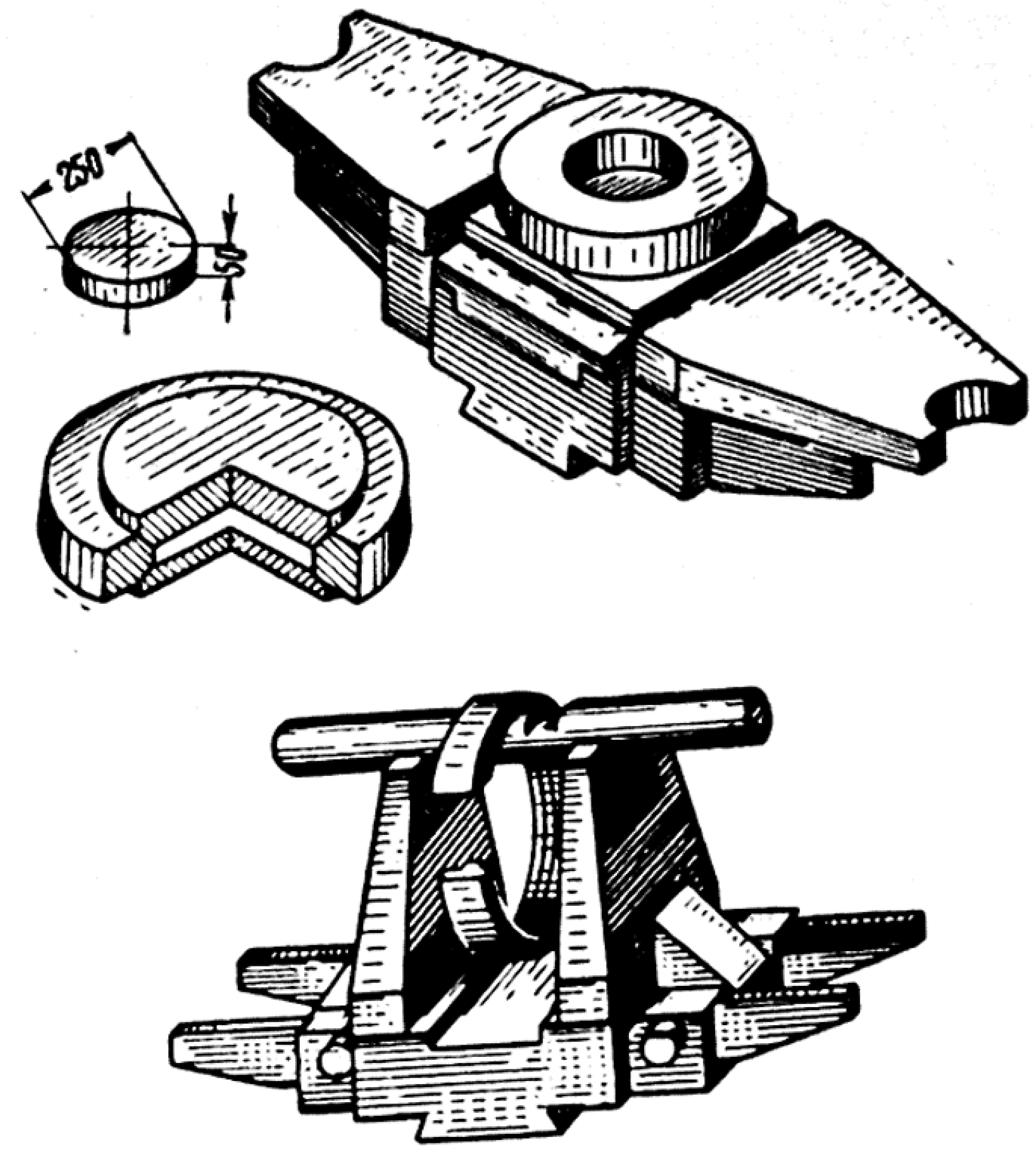
Rotor ring, forged according to new technological process



Specifications of forging: Weight of stock—385.5 kg.
Weight of forging—340 kg.
Material: Steel—grade ЩХ15СГ
No. of heatings required: 2

New method

No	Description of operation	Sketch of pass	Tool	Average time
1	Place heated bar stock onto bottom die of hammer, cut to stock lengths, gather cut stock and charge into furnace		Flat top die, recessed bottom die, hot-sets, cutter, levers, rule, folding rule	4 minutes

2	Place stock on bottom die of hammer, upset stock, punch hole, straighten, taper-forge inner hole of ring to required diameter, roll ring to forging dimensions on special mandrel. Reset and adjust device, flatten faces to height		Combination bottom dies, special mandrel, punch, spherical swage, calipers	24 minutes 50 seconds

Total time — 28 min. 50 sec.

Economical effect per forging:

1. Reduction of machining allowance for inside diameter results in saving 100 kg of steel per forging; utilisation of slug for other forgings—economy of 19 kg of steel per forging. Total economy of metal—119 kg
2. Use of combination bottom saddle-die eliminates two heatings. Fuel saving of 37.5 kg;
3. Economy of auxiliary time: in charging and discharging stock into and from furnace—6 min. 20 sec.; in adjusting die: 45 min.

CHAPTER XVII

SAFETY ENGINEERING

SAFETY ENGINEERING ON THE TERRITORY OF AN ENTERPRISE

In order to ensure safety during work and reduce industrial accidents to a minimum, *it is necessary*: a) to organise the production processes properly; b) to organise each working place rationally; and c) to observe strictly all labour safety laws and all safety engineering rules and regulations during work.

The *most important safety rule* is never to begin work on any equipment unless it is known how it operates. Before proceeding to execute a new operation, or before commencing to work on a machine or equipment which has not been previously operated, the worker must always be instructed in the methods of safe operation and in the rules and regulations for operating the machine or equipment. It must always be remembered that the chief danger is not in the hammer, hearth, furnace or other equipment as such, but in its unskilled or careless handling and operation.

Each forge shop is but one of many production departments of a plant and, as such, has communications (transport, water and power supplies, etc.) with other departments and services of the plant. Therefore, every blacksmith must know the safety rules, not only of his own department, but also those observed everywhere in the plant in which he is employed. The *chief rules* which every worker of every plant must observe are the following:

1. Never cross a railway track when the barrier is down or when the approach of a train has been signalled. Barriers are installed where railway tracks and roads cross to close the road to pedestrians before the passage of trains, locomotives or automobile traffic. In addition to barriers, sound or light signals are installed to warn pedestrians of approaching traffic.

2. The factory area must be level, without any ditches, etc. Many installations, however, are always laid underground (sewerage lines, water, steam and power mains, etc.). These installations are regularly examined, cleaned and repaired; for this purpose it may be necessary to dig deep pits or trenches, and to prevent the possibility of people accidentally falling into them; they are generally surrounded by barriers, bearing warnings as, for instance, "No thoroughfare". Never

climb over such barriers or even cross places bearing such warnings.

3. As a rule, the territory of the plant should be illuminated at night. It does happen, however, that the lights in some sections of the territory may be temporarily cut off (due to repairs of the mains, or the failure of a light, etc.). When walking through darkened sections, be very careful. It is better to find a path which is illuminated than to walk along darkened sections.

4. Every plant has certain premises and departments, admittance to which is strictly forbidden to unauthorised persons (these include electric power sub-stations, compressor stations, etc.). Never enter any premises bearing the sign "No admittance" without special permission from the plant or department management. A worker of the forge department may not enter any other departments of his plant (such as, for instance, the machine shop) if he has no business there, and without the permission of the department or plant administration. As workers of the forge department are unacquainted with the features of the work and safety rules of other departments, they will only be placing themselves in danger by visiting such departments without permission.

5. As a rule, smoking is prohibited on the territory of most enterprises; special rooms or areas are allotted for smoking. Non-observance of smoking regulations may lead to fires, and smoking in places where highly inflammable substances, such as petrol, are stored may cause explosions leading to the death, not only of smokers themselves, but of many other workers not to mention the considerable damage which the state may suffer.

6. Loading and unloading operations are carried out in definite places on the factory territory; they are usually executed with the aid of cranes and other mechanisms. Special care must be observed in such places. To avoid accidents, never stand under any suspended load.

These are only a few of the rules which every worker must unfailingly observe whenever he is on the territory of any plant.

Each factory has its own safety rules and regulations which differ to some extent from those of other factories; for this reason, every worker, in addition to observing the above-mentioned six general rules, must also observe all other safety rules and regulations of the factory where he works.

FIRST AID IN CASE OF ACCIDENTS. MEDICAL AND SANITARY SERVICE

In case of accident, the victim must always immediately go to the first-aid station if the injury is slight or, if it is serious, his fellow-workers must see that he is taken there. If this cannot be done for any reason, a doctor or nurse must be immediately called. First aid,

however, must be given in any case. Every worker must know how to help himself or others in case of accident.

Dressings. Every wound, however slight, must be kept particularly clean in order to prevent blood poisoning. If a worker has been wounded, take one of the individual first-aid packets from the medicine chest in the shop, remove a bandage and dress his wound without the loss of any time. In case of severe bleeding, place an extra pad above the wound and tightly bandage it with a towel or handkerchief. Never wash a wound with water.

Bruises. In case of slight external bruises, place a cold-water compress on the bruised spot, and give the bruised limb or part of the body as much rest as possible. If the bruise is severe, and internal organs of the body are affected, the victim must be carefully placed on a stretcher or a bed, after loosening or removing all tight clothes, and the doctor must be sent for as quickly as possible. Place cold compresses on the bruise until the doctor arrives.

Fractured Bones. Should a leg be broken, place the victim on a stretcher or on the ground and bandage the fracture with splints made of boards, cardboard and the like. Such a dressing will prevent the ends of fractured bone from shifting and will ease the pain. Broken arms should be bandaged in the same way, but there is no need to put the victim on a stretcher.

Injuries to the Eyes. Never rub your eye if a particle of dust, filing, chip of metal, etc., has fallen into it. If you cannot take it out of your eye yourself, go to the doctor immediately.

Electric Shocks. The first thing to do when anyone has suffered an electric shock, is to cut off the current either with the switch, or by cutting the electric wires with a dry wooden-handled tool, such as an axe. The person doing this must be well-insulated from the ground, otherwise he too may suffer an electric shock. For this reason, never stand on bare, and, especially, on wet soil when doing this. Always put on rubber galoshes and rubber gloves; if these are not readily available, stand on a stone or on a dry board. Only after the victim has been released from the current can first aid be applied to him.

If the victim is unconscious, place him on his back, loosen all his clothes, open all the doors and windows and send for the doctor immediately. Meanwhile, until the doctor arrives, artificial breathing may be resorted to. Artificial breathing is applied to the victims of electric shock not only when they display signs of life, but also when they display no signs of life whatsoever. This is necessary, because, in the majority of cases, what may appear as death from electric shock is only a deep faint.

Burns. Place a sodium bicarbonate compress (one table spoon full of soda per glass of water) on the burn or bathe it with a lead lotion.

If neither sodium bicarbonate nor lead lotion are available, dress the burn with a clean bandage and apply immediately to the first-aid station.

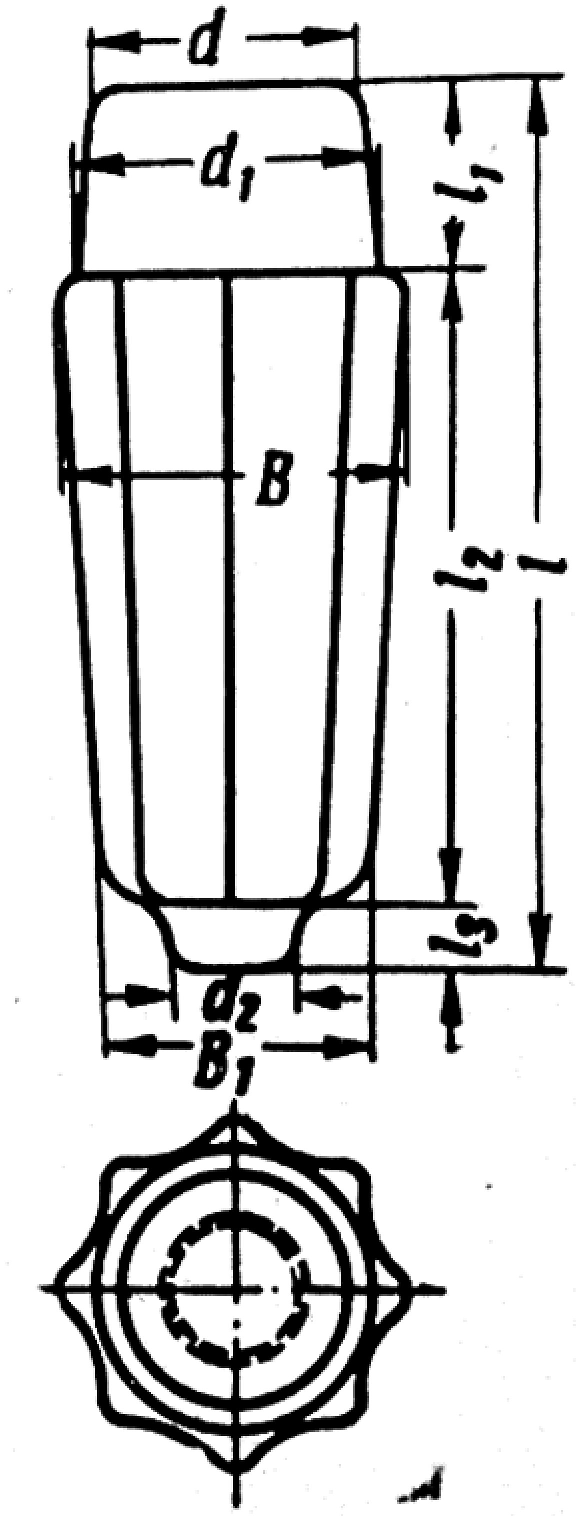
Heat Stroke. Heat strokes may occur if the body is severely overheated. The victim shows signs of fainting, his pulse weakens and, in some cases, convulsions appear.

In cases of heat stroke, remove the victim to a cool place, loosen his clothes, sprinkle his chest and face with cold water and place cold compresses on his body. If he does not breathe, resort to artificial breathing and send to the first-aid station immediately for a doctor or a nurse.

APPENDIX 1

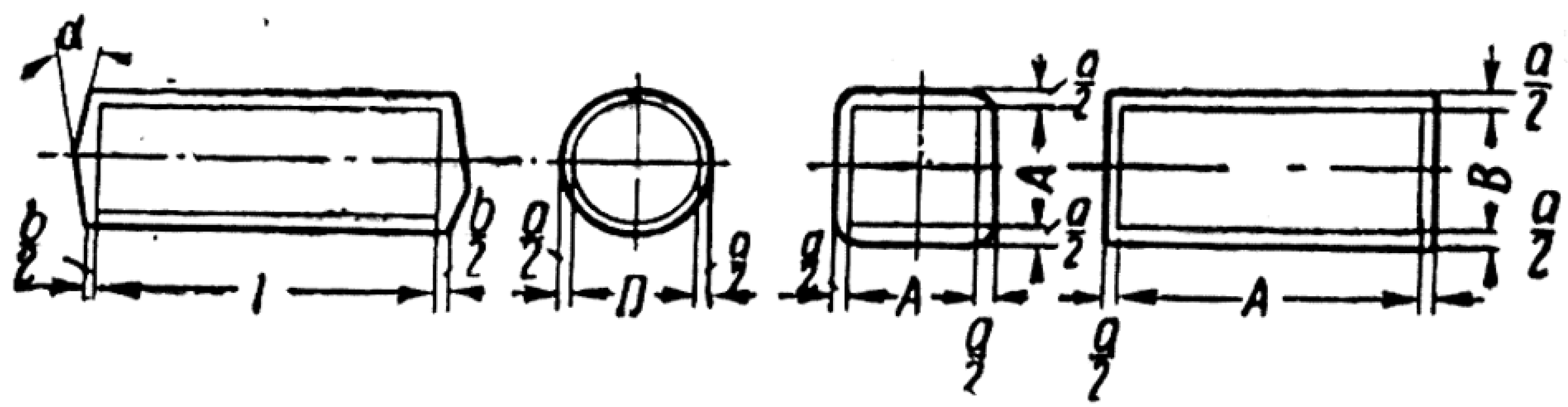
Dimensions and Weights of Ingots

No	Weight, kg			Dimensions, mm									Cross-section	Sketch
	Total	Head discard	Bottom discard	l	l_1	l_2	l_3	d	d_1	d_2	B	B_1		
1	1,250	265	10	1,400	370	1,000	30	325	400	140	455	385	Round, square	
2	2,165	450	15	1,600	400	1,150	50	430	500	200	550	400	Ditto	
3	3,250	650	25	1,800	450	1,350	60	500	580	250	630	500	Square, poly-hedral	
4	3,791	758	93	1,926	410	1,400	116	535	610	296	670	585	Poly-hedral	
5	5,120	1,155	105	2,096	455	1,526	116	693	670	296	730	635	Ditto	
6	6,413	1,270	173	2,266	500	1,650	116	630	723	296	795	695	Ditto	
7	9,149	1,820	219	2,527	560	1,825	142	720	825	397	895	785	Ditto	
8	12,671	2,490	251	2,682	600	1,940	142	815	930	397	1,000	915	Ditto	
9	15,606	3,100	306	2,832	640	2,050	142	875	1,000	397	1,070	980	Ditto	
10	18,581	3,790	331	3,027	690	2,195	142	981	1,065	397	1,135	1,040	Ditto	
11	26,328	5,200	578	3,574	770	2,420	184	1,040	1,185	542	1,265	1,155	Ditto	
12	32,368	6,600	668	3,644	840	2,620	184	1,220	1,275	542	1,365	1,250	Ditto	
13	46,013	9,950	763	4,044	940	2,920	184	1,277	1,440	542	1,520	1,395	Ditto	
14	52,631	10,850	1,081	4,250	980	3,060	210	1,325	1,510	623	1,600	1,460	Ditto	
15	58,123	12,100	1,123	4,425	1,025	3,190	210	1,375	1,560	623	1,650	1,505	Ditto	
16	63,000	12,600	1,400	4,480	950	3,230	300	1,420	1,560	500	1,630	1,515	Ditto	
17	72,159	15,200	1,259	4,700	1,100	3,390	210	1,491	1,685	623	1,775	1,620	Ditto	
18	85,410	16,000	1,419	4,991	1,170	3,600	221	1,576	1,780	623	1,880	1,720	Ditto	
19	97,722	20,800	1,522	5,221	1,230	3,770	221	1,656	1,860	623	1,970	1,800	Ditto	
20	118,664	25,000	2,664	5,531	1,310	4,000	221	1,756	1,980	623	2,090	1,910	Ditto	
21	145,000	23,850	3,840	6,015	1,450	4,150	415	1,645	1,890	800	2,280	2,070	Ditto	
22	170,000	35,800	3,174	6,460	1,490	4,525	445	1,975	2,200	802	2,360	2,150	Ditto	
23	215,000	47,000	7,700	6,837	1,625	4,900	312	2,184	2,430	828	2,560	2,325	Ditto	
24	250,000	53,750	10,390	7,744	2,020	5,100	624	2,280	2,530	768	2,700	2,450	Ditto	



APPENDIX 2

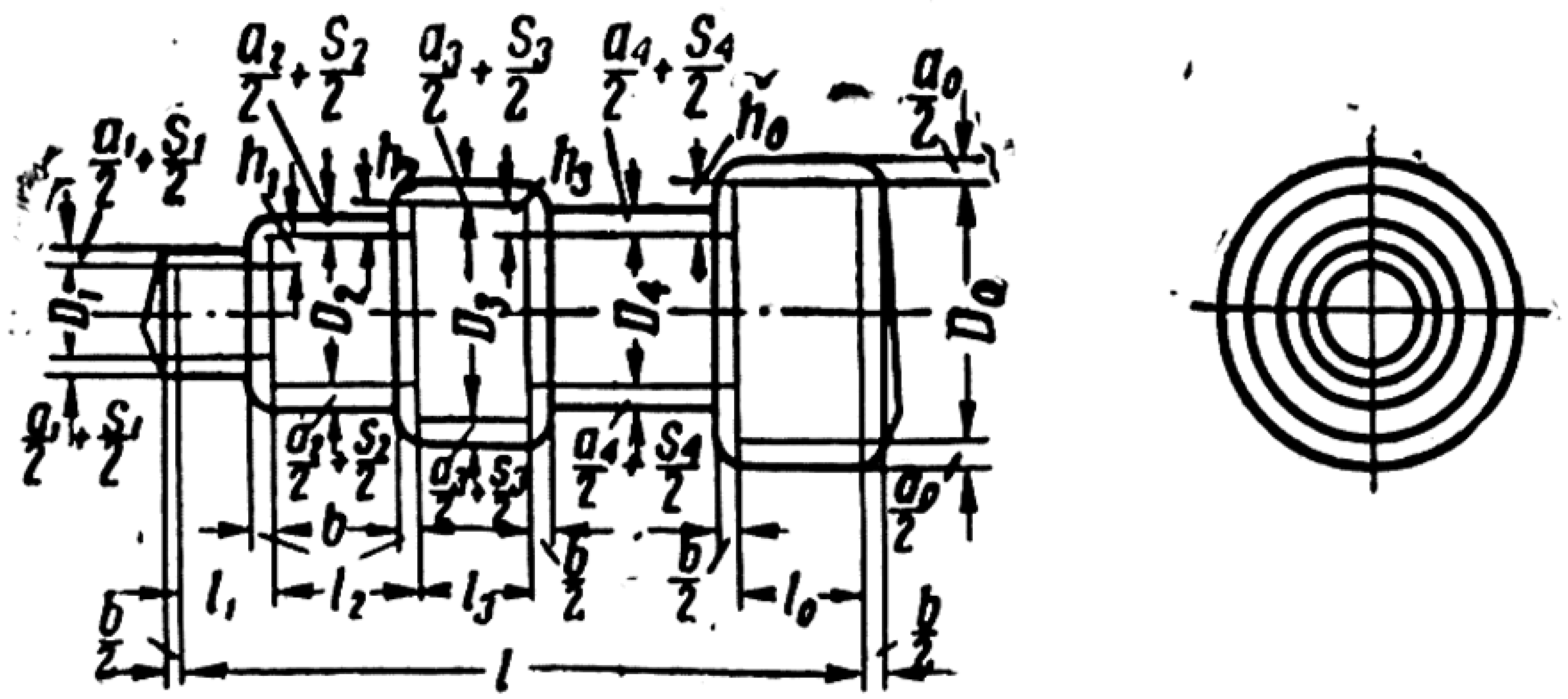
Allowances and Tolerances for Solid Smooth Forgings of Round and Rectangular Cross-Section (mm)



Length of forging	Dimensions on which allowances and tolerances are specified	Diameter D, or dimensions A and B of cross-section					
		25-50	51-80	81-120	121-180	181-250	251-300
		Allowances a and b and deviations					
Up to 250	For D, A, and B	5^{+1}_{-2}	6 ± 2	8 ± 3	—	—	—
	For l	15 ± 6	18 ± 6	24 ± 8	—	—	—
251-500	For D, A, and B	6 ± 2	8^{+2}_{-3}	9 ± 3	10 ± 3	12^{+3}_{-4}	14^{+4}_{-5}
	For l	18 ± 6	24 ± 8	27 ± 10	30 ± 10	36 ± 12	42 ± 12
501-800	For D, A, and B	7 ± 2	9^{+2}_{-3}	10 ± 3	11^{+3}_{-4}	13 ± 4	15 ± 5
	For l	20 ± 6	27 ± 10	30 ± 10	33 ± 12	40 ± 12	45 ± 15
801-1,250	For D, A, and B	8 ± 2	10^{+2}_{-3}	11^{+3}_{-4}	12 ± 4	14^{+4}_{-5}	16 ± 5
	For l	24 ± 8	30 ± 10	33 ± 12	36 ± 12	42 ± 15	48 ± 15
1,251-2,000	For D, A, and B	10^{+2}_{-3}	11 ± 3	12^{+3}_{-4}	14 ± 4	15^{+4}_{-5}	18 ± 5
	For l	30 ± 10	33 ± 10	36 ± 12	42 ± 12	45 ± 15	54 ± 15
2,001-2,500	For D, A, and B	$12+2$	13 ± 3	14^{+3}_{-4}	16^{+4}_{-5}	17 ± 5	—
	For l	36 ± 10	39 ± 10	42 ± 12	43 ± 15	51 ± 15	—

APPENDIX 3

Solid Stepped Forgings of Round and Square Cross-Section (all dimensions in mm)



Total length, l	Section for which allowances and deviations are specified	Diameters D_0, D_1, D_2, D_3, D_4					
		25-50	51-80	81-120	121-180	181-250	251-360
		allowances a_0, a_1, a_2, a_3, a_4 and b, and deviations					
up to 250	For D_0, D_1, D_2, D_3 of necks and shoulders	5^{+1}_{-2}	6 ± 2	8 ± 3	8 ± 3	—	—
	For D_4 of steps	5 ± 2	7 ± 3	9^{+4}_{-5}	9^{+5}_{-4}	—	—
	For length l	15 ± 6	18 ± 6	24 ± 8	24 ± 8	—	—
251-500	For D_0, D_1, D_2, D_3 of necks and shoulders	6 ± 2	8^{+2}_{-3}	9 ± 3	10 ± 3	12^{+3}_{-4}	14^{+4}_{-5}
	For D_4 of steps	7^{+4}_{-3}	8^{+3}_{-4}	10^{+5}_{-4}	11^{+5}_{-4}	13 ± 5	15^{+7}_{-6}
	For length l	18 ± 6	24 ± 8	27 ± 10	30 ± 5	36 ± 12	42 ± 12

APPENDIX 3 (continued)

Total length, l	Section for which allowances and deviations are specified	Diameters D_0, D_1, D_2, D_3, D_4					
		25-50	51-80	81-120	121-180	181-250	251-360
		Allowances a_0, a_1, a_2, a_3, a_4 and b, and deviations					
501-800	For D_0, D_1, D_2, D_3 of necks and shoulders	7 ± 2	9^{+2}_{-3}	10 ± 3	12^{+3}_{-4}	13 ± 4	15 ± 5
	For D_4 of steps	8 ± 3	9^{+4}_{-3}	11^{+5}_{-4}	13 ± 5	15 ± 6	17^{+8}_{-7}
	For length l	20 ± 6	27 ± 8	30 ± 10	36 ± 12	40 ± 12	45 ± 15
801-1,250	For D_0, D_1, D_2, D_3 of necks and shoulders	8 ± 2	10^{+2}_{-3}	12^{+3}_{-4}	13 ± 4	15^{+4}_{-5}	16 ± 5
	For D_4 of steps	9 ± 3	10^{+4}_{-3}	13 ± 5	15 ± 6	16^{+7}_{-6}	18^{+8}_{-7}
	For length l	24 ± 8	30 ± 10	36 ± 12	40 ± 12	45 ± 15	48 ± 15
1,251-2,000	For D_0, D_1, D_2, D_3 of necks and shoulders	10^{+2}_{-3}	11 ± 3	13^{+3}_{-4}	14 ± 4	16^{+4}_{-5}	17 ± 5
	For D_4 of steps	10^{+4}_{-3}	12^{+5}_{-4}	14 ± 5	16 ± 6	17^{+7}_{-6}	19^{+8}_{-7}
	For length l	30 ± 10	33 ± 10	40 ± 12	42 ± 12	48 ± 15	50 ± 15
2,001-2,500	For D_0, D_1, D_2, D_3 of necks and shoulders	11^{+2}_{-3}	12 ± 3	14^{+3}_{-4}	16^{+4}_{-5}	17 ± 5	19^{+5}_{-6}
	For D_4 of steps	11^{+4}_{-3}	13^{+5}_{-4}	15 ± 5	17^{+7}_{-6}	19^{+8}_{-7}	21 ± 8
	For length l	33 ± 10	36 ± 12	42 ± 12	48 ± 15	50 ± 15	57 ± 20
2,501-3,150	For D_0, D_1, D_2, D_3 of necks and shoulders	—	14 ± 3	15 ± 4	16^{+4}_{-5}	17 ± 5	19^{+5}_{-6}
	For D_4 of steps	—	15^{+5}_{-4}	17 ± 6	17^{+7}_{-6}	19^{+8}_{-7}	21 ± 8
	For length l	—	42 ± 12	45 ± 12	48 ± 15	50 ± 15	57 ± 20

APPENDIX 4

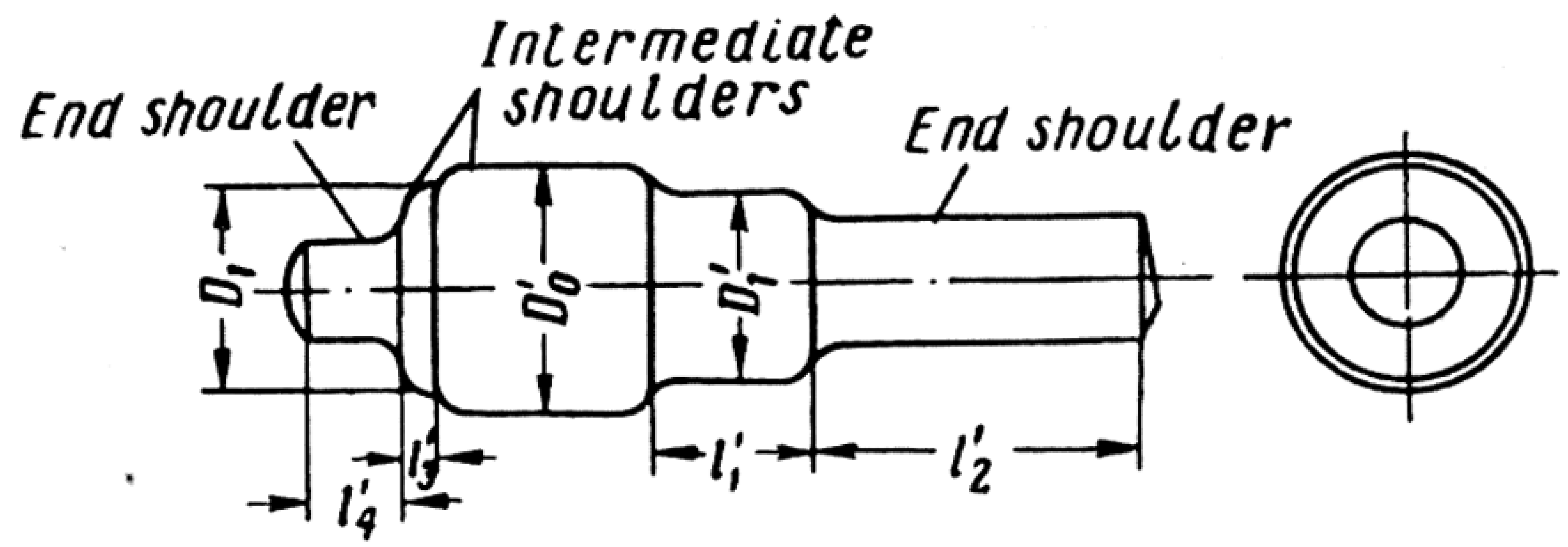
Stepped Forgings of Round and Square Cross-Section (all dimensions in mm)
See Appendix 3 for Explanation of Symbols of Sketch of Forging

Difference between maximum diameter D_0 and diameters D_1, D_2, D_3, and D_4 of section (step) under consideration D_0-D_1; D_2; D_3 and D_4	Additional allowances S_1, S_2, S_3, S_4	Diameters under consideration D_1, D_2, D_3, D_4	When ratio $\frac{l_1, l_2, l_3, l_4}{l_0}$ is equal to or less than value specified in this column, add additional allowances S_1, S_2, S_3 and S_4 for diameters D_1, D_2, D_3, and D_4 respectively; if this ratio is greater than value specified in this column — add additional allowance to diameter D_0
10-40	3	up to 50 51-80 81-120 121-180 181-250 over 250	2.00 1.40 1.25 1.15 1.10 1.10
41-80	4	up to 50 51-80 81-120 121-180 181-250 over 250	3.40 1.90 1.60 1.40 1.30 1.20

Difference between maximum diameter D_0 and diameters D_1, D_2, D_3, and D_4 of section (step) under consideration D_0-D_1; D_2; D_3 and D_4	Additional allowances S_1, S_2, S_3, S_4	Diameters under consideration D_1, D_2, D_3, D_4	When ratio $\frac{l_1, l_2, l_3, l_4}{l_0}$ is equal to or less than value specified in this column, add additional allowances S_1, S_2, S_3 and S_4 for diameters D_1, D_2, D_3 and D_4 respectively; if this ratio is greater than value specified in this column — add additional allowance to diameter D_0
81-120	6	up to 50 51-80 81-120 121-180 181-250 over 250	3.50 2.60 2.00 1.70 1.50 1.40
121-180	8	up to 80 81-120 121-180 over 180	3.40 2.55 2.00 1.75
181-280	10	up to 80 81-120 over 120	4.00 3.25 2.50

APPENDIX 5

Maximum Lengths of End and Intermediate Forged Steps (all dimensions in mm)

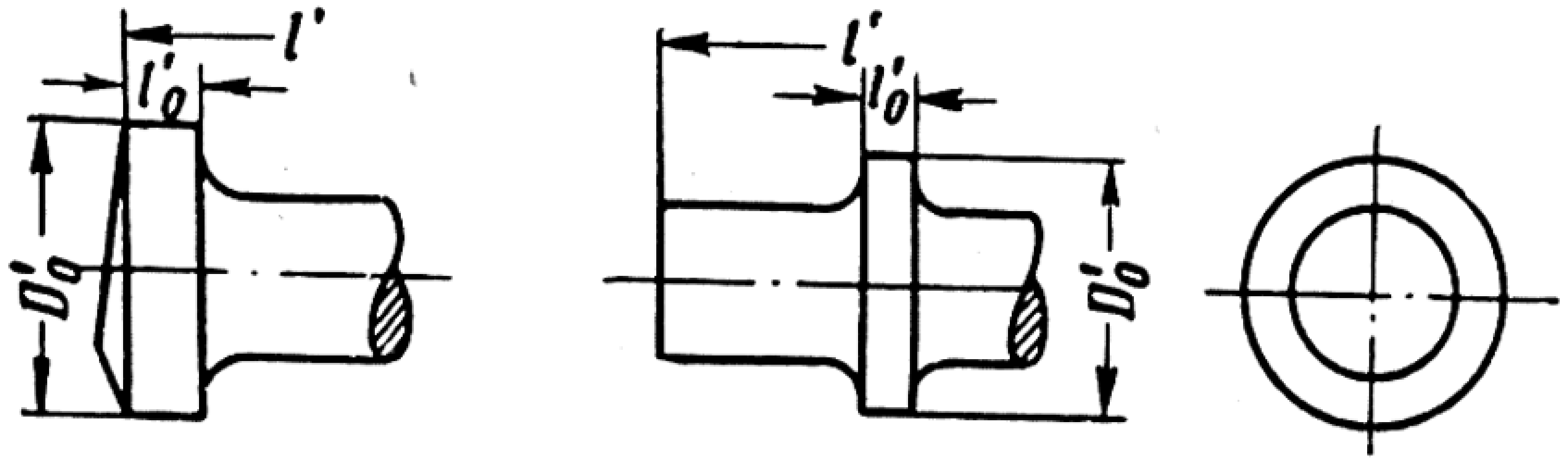


Section	Diameter D_0' or D_1', adjacent to neck under consideration													
	up to 40	41-50	51-60	61-70	71-80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	221-250	251-280	281-360
a) Maximum length l'_1, l'_2, l'_3, l'_4 of step which is not formed on forging, but formed on section adjacent to that under consideration															
End neck	15	15	20	25	30	35	40	45	50	55	65	75	85	90	100
Intermediate neck . . .	10	10	15	20	25	30	35	35	40	45	50	60	70	75	80
b) Maximum length l'_1, l'_2, l'_3, l'_4 of step formed on forgings															
End neck	25	30	35	40	45	50	60	70	80	90	100	115	130	150	180
Intermediate neck . . .	20	25	28	30	35	40	50	55	65	70	80	90	105	120	150
c) Necks having intermediate lengths l'_1, l'_2, l'_3, l'_4 are forged, but with lengths not less than indicated in part *b* of this table															

Notes: 1. The dimensions D'_0, D'_1, l'_1, l'_2, l'_3, l'_4 are given with allowances specified in Appendices 3 and 4.
2. Appendix 5 refers only to drawn-out forgings.
3. Appendix 5 refers to forgings with square or round steps.
4. For square section forgings, take lengths of opposite sides of squares instead of diameter D'_0; for length l_1 take length of opposite side of square.

APPENDIX 6

Maximum Length l'_0 of End Shoulder (Flange) and Width l'_0 of Collar Formed on Forgings (all dimensions in mm)



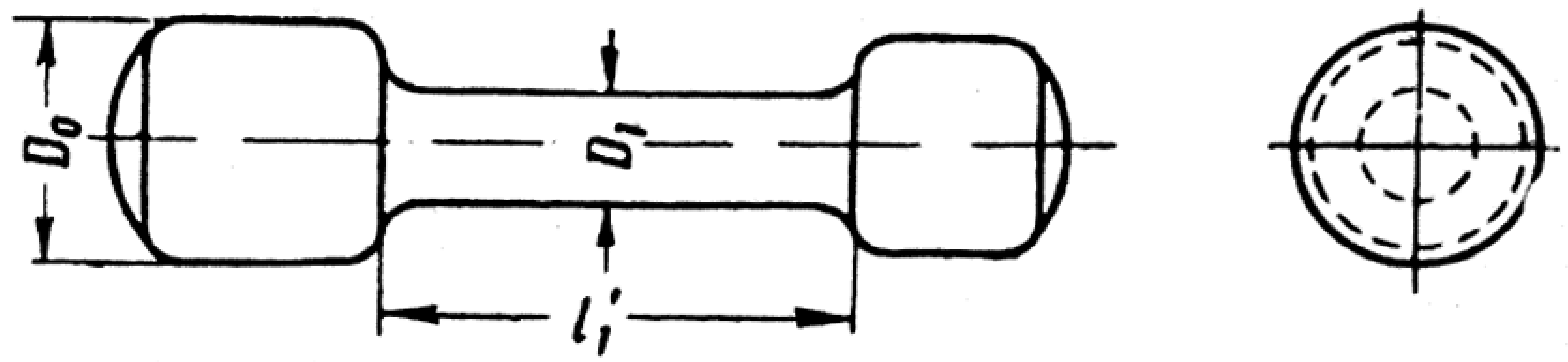
D'_0, l', and l'_0 — dimensions and allowances specified in Appendices 3 and 4

Total length l'_1 of forging	Diameter D'_0 of end shoulder (flange) or collar													
	up to 50	51-60	61-70	71-80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	221-250	251-280	281-360
Minimum length of end collar (flange) l'_0 formed on forgings														
Up to 500	20	20	22	25	30	30	35	38	45	50	60	65	75	90
501-1,000	22	25	25	30	35	40	45	50	60	65	75	85	100	120
Over 1,000	25	30	30	35	45	50	60	70	75	85	95	110	125	150
Minimum width of collar l'_0 formed on forgings														
Up to 500	12	15	15	15	20	20	22	25	30	35	40	45	50	60
501-1,000	15	15	18	20	25	25	30	35	40	45	50	60	70	80
Over 1,000	15	20	20	25	30	35	40	45	50	55	65	75	85	100

Notes: 1. Appendix 6 refers to drawn-out forgings only;
2. If the length of the end shoulder (flange) or of the width of the collar is less than that indicated in Appendix 6, it is to be increased by an additional allowance in the direction of the adjacent section until it reaches the corresponding length specified in the appendix;
3. Appendix 6 also refers to square section forgings; in this case, take lengths of opposite sides of square instead of D_0.

APPENDIX 7

Minimum Dimensions of Necks to be Formed on Forgings (all dimensions in mm)



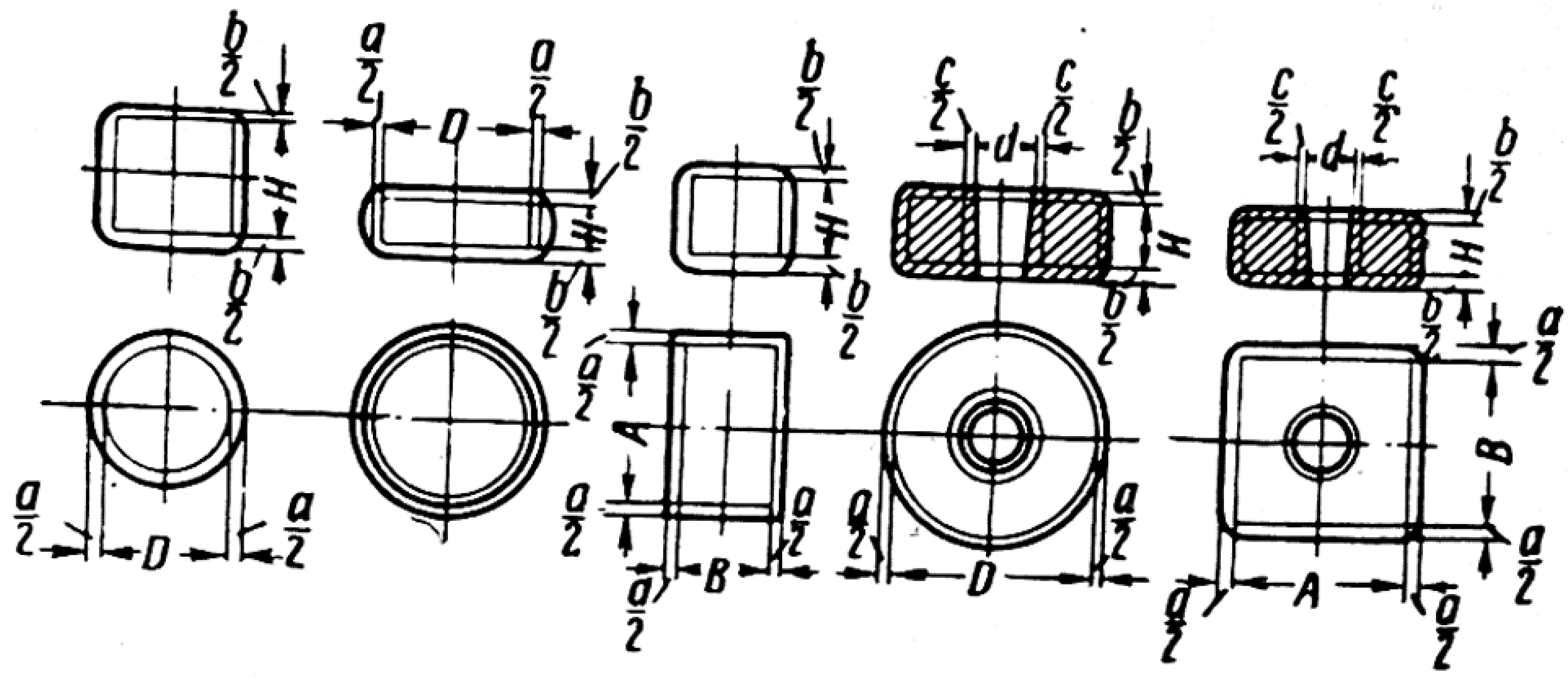
D_0', D_1', l_1' — dimensions of forging together with allowances are specified according to Appendices 3 and 4

Length l'_0 of neck	Diameter D'_0 of greatest section													
	30-50	51-60	61-70	71-80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	221-250	251-280	281-360
	Maximum forged diameter of neck, D_1'													
Up to 70	Neck is not forged, or only squeezed													
71-100	35													
101-120	32	40												
121-160	30	35	45	50	70									
161-180	25	32	40	45	65	80	95							
181-200	25	30	35	45	60	75	90	110						
201-250	25	30	32	40	55	70	85	100	120					
251-280	20	25	30	35	50	65	75	90	110	120				
281-360	20	25	25	30	45	60	70	85	100	110	125	145		
361-400	20	20	25	30	40	55	65	80	90	100	120	130	150	
401-500	15	20	25	30	40	50	60	70	85	95	110	120	140	190
501-600	15	20	20	25	35	45	50	65	75	85	100	110	130	170
601-750	12	15	20	25	30	40	50	60	70	80	90	100	115	155
751-1,000				20	30	35	45	50	60	70	80	90	105	140
Over 1,000							40	45	55	60	70	80	90	120

Notes: 1. If the diameter of the neck is less than that specified in this table, an additional allowance must be added to the diameter of the neck, i. e., the diameter of the neck must be increased to the corresponding value in the table; if it is greater than that specified in this table, the neck must be forged to dimensions specified in the table;
2. Appendix 7 also refers to forgings of square section. In these cases, take lengths of opposite sides of square instead of diameters D'_0 and D_1';
3. This appendix refers only to drawn-out forgings.

APPENDIX 8

Allowances and Tolerances for Forgings — Cylinders, Discs, Bars, Plates — Solid or with Holes (all dimensions in mm)



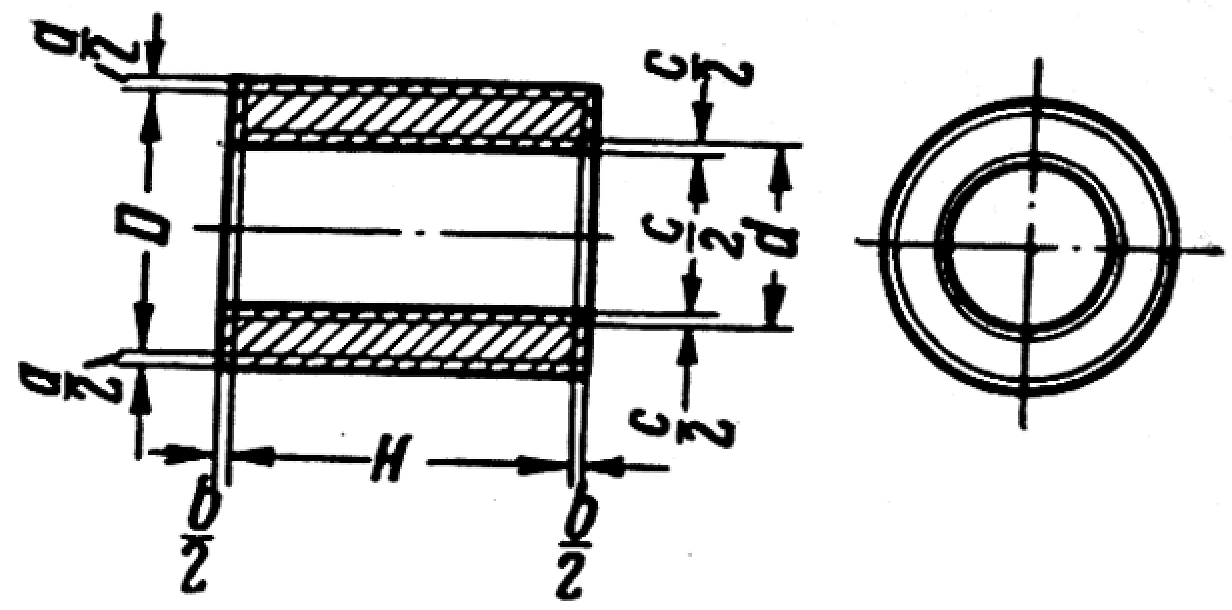
Height of forging, H	Diameter D or dimension A	Allowances a, b, and c and tolerances				
		on height H	On dimensions D, A and B	On diameter of hole d — For difference D-d or A-d: 50-120	121-300	301 and over
Up to 50	Up to 50	7 ± 2	7 ± 2	—	—	—
	51-80	7 ± 2	8 ± 2	—	—	—
	81-120	7 ± 2	9 ± 2	14 ± 2	—	—
	121-180	7 ± 2	10 ± 2	15 ± 2	—	—
	181-250	8^{+2}_{-3}	11^{+2}_{-3}	16^{+3}_{-2}	17 ± 3	—
	251-360	9^{+2}_{-3}	13 ± 4	—	19 ± 4	—
	360-500	10 ± 3	15 ± 5	—	21 ± 5	22 ± 5
51-80	Up to 50	7 ± 2	7 ± 2	—	—	—
	51-80	8 ± 2	8 ± 2	—	—	—
	81-120	8 ± 2	10 ± 2	15 ± 2	—	—
	121-180	8 ± 2	11^{+2}_{-3}	16^{+3}_{-2}	—	—
	181-250	9^{+2}_{-3}	12^{+2}_{-3}	17^{+3}_{-2}	18^{+3}_{-2}	—
	251-360	11 ± 3	14 ± 4	—	20 ± 4	—
	361-500	12 ± 4	16 ± 5	—	22 ± 5	23 ± 5
	501-630	14 ± 5	19 ± 7	—	25 ± 7	26 ± 7

APPENDIX 8 (continued)

Height of forging, H	Diameter D or dimension A	Allowances a, b and c and tolerances				
		on height H	On dimensions D, A, and B	On diameter of hole d		
				For difference D-d or A-d		
				50-120	121-300	301 and over
80-120	Up to 80	9 ± 2	9 ± 2	—	—	—
	81-120	11 ± 3	11 ± 3	16 ± 3	—	—
	121-180	11 ± 3	12 ± 3	17 ± 3	—	—
	181-250	12^{+3}_{-4}	14^{+3}_{-4}	19^{+4}_{-3}	20^{+4}_{-3}	—
	251-360	13 ± 4	16 ± 4	—	20 ± 4	—
	361-500	13 ± 4	18 ± 5	—	24 ± 5	25 ± 5
	501-630	16 ± 6	20 ± 7	—	26 ± 7	27 ± 7
121-180	Up to 120	12 ± 3	12 ± 3	17 ± 3	—	—
	121-180	13 ± 4	13 ± 4	18 ± 4	—	—
	181-250	14 ± 5	16 ± 5	21 ± 5	22 ± 5	—
	251-360	15 ± 5	18 ± 5	—	24 ± 5	—
	361-500	15 ± 5	20 ± 6	—	26 ± 6	27 ± 6
	501-360	17 ± 6	22 ± 8	—	28 ± 8	29 ± 8
181-250	Up to 180	14 ± 5	14 ± 5	19 ± 5	—	—
	181-250	17 ± 6	17 ± 6	22 ± 6	23 ± 6	—
	251-360	18 ± 6	19 ± 6	—	25 ± 6	—
	361-500	18 ± 6	21 ± 7	—	27 ± 7	28 ± 7
	501-630	19 ± 7	24 ± 8	—	30 ± 8	31 ± 8

APPENDIX 9

Forging — Hollow Cylinders (all dimensions in mm)



Height H	Diameter D	Allowances a, b and c, and deviations				
		on height H	On outer diameter D	On diameter of hole, d — For difference D-d		
				up to 60	61-130	131-180
60-120	60-120	14±5	14±4	17±4	—	—
121-180	60-180	17±6	16±5	19±5	20±5	—
181-250	120-250	19±6	18±6	22±6	22±6	23±6
251-360	180-250	22±8	23±7	26±7	27±8	28±8
	251-360	24±10	23±7	26±7	27±8	28±8
361-530	250-360	27±10	25±9	28±9	29±9	30±9

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